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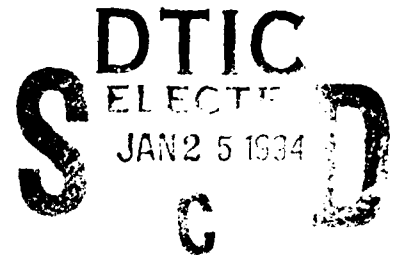


Technical Report ITL-92-12  
December 1993

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*Computer-Aided Structural Engineering (CASE) Project*

## **Computer-Aided, Field-Verified Structural Evaluation**



### **Report 3**

## **Field Test and Analysis Correlation of a Vertically Framed Miter Gate at Emsworth Lock and Dam**

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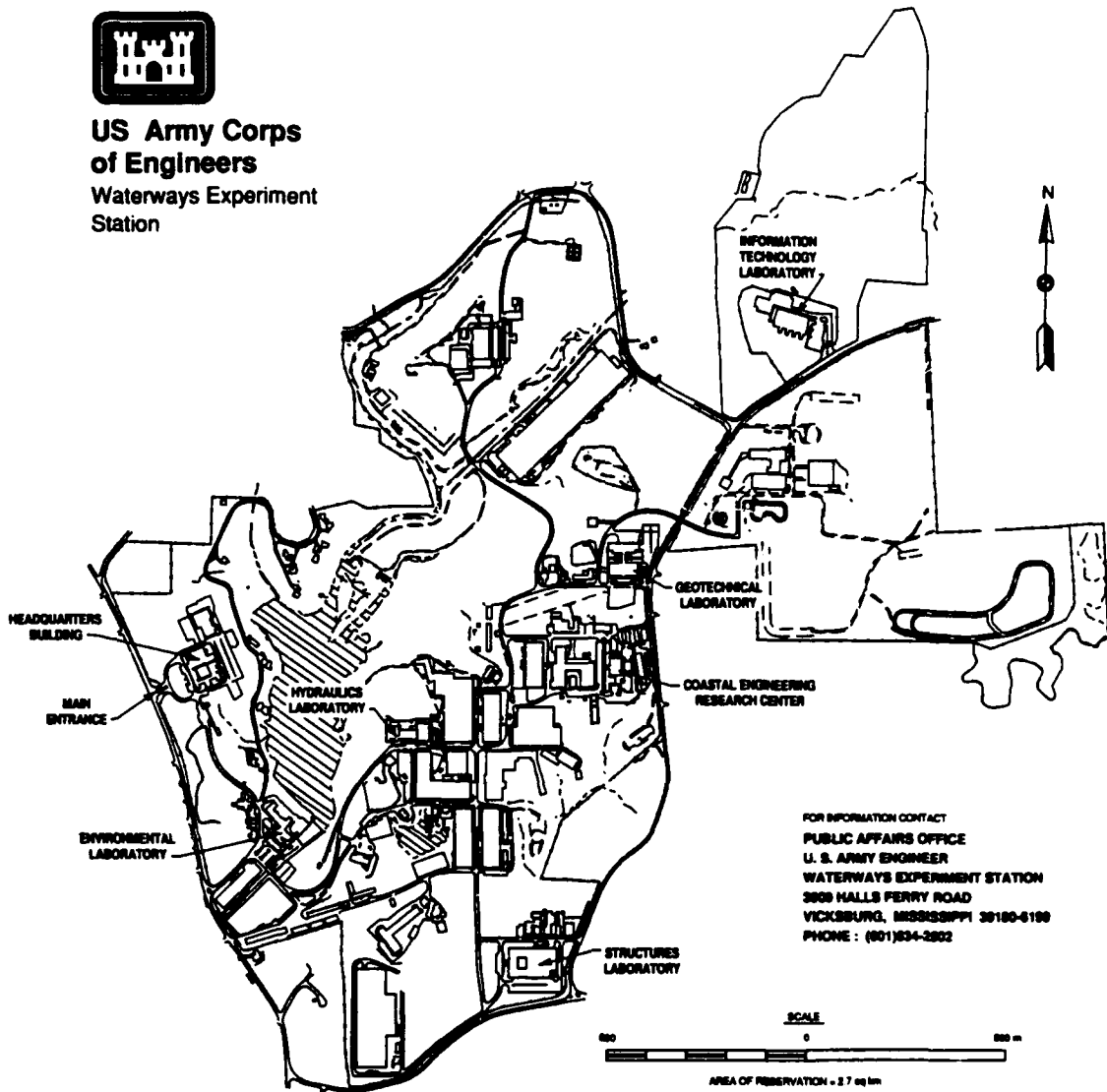


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# Preface

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This report is the third of a series which describes the research conducted as part of a Computer-Aided Structural Engineering (CASE) Project effort entitled "Computer-Aided, Field-Verified Structural Evaluation." The CASE Project is managed by the Scientific and Engineering Applications Center (S&EAC) of the Computer-Aided Engineering Division (CAED), Information Technology Laboratory (ITL), U.S. Army Engineer Waterways Experiment Station (WES). The CASE Project is funded by the Civil Works Directorate, Headquarters, U.S. Army Corps of Engineers (HQUSACE). Mr. Cameron P. Chasten, ITL, WES, was project manager under the general supervision of Mr. H. Wayne Jones, Chief, S&EAC, ITL, WES, and Dr. N. Radhakrishnan, Director, ITL, WES.

The work was performed by Bridge Diagnostics Incorporated (BDI) under U.S. Army Corps of Engineers (USACE) contract number DACW39-91-C-0102. The report was prepared by Mr. Brett C. Commander, Mr. Jeff X. Schulz, and Dr. George G. Goble, all of BDI, and Mr. Chasten. Acknowledgement is expressed to Mr. Bruce Riley, U.S. Army Engineer District, Pittsburgh (CEORP-ED-DS), for providing arrangements for field testing performed at the Emsworth Lock and Dam.

At the time of publication of this report, Director of WES was Dr. Robert W. Whalin. Commander was COL Bruce K. Howard, EN.

# Conversion Factors, Non-SI to SI Units of Measurement

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Non-SI units of measurement used in this report can be converted to SI units as follows:

Multiply	By	To Obtain
feet	0.3048	meters
inches	0.0254	meters
kip foot	1355.818	newton-meter
kips per square inch (ksi)	6894.757	kilopascals



# 1 Introduction

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The primary goal of this project is to develop a simple miter gate evaluation system that combines experimental and analytical tools. In Report 1 of this project (Commander et al. 1992a), development of general modeling procedures for analyzing horizontally and vertically framed miter lock gates was described. Report 2 of this project (Commander et al. 1992b) describes experimental and analytical studies conducted for a horizontally framed miter gate. Four modeling approaches, each involving various geometric simulations were developed during these previous studies. These included three different finite element grid models of various geometry and complexity, and a three-dimensional (3-D) finite element model. Based on overall performance and simplicity of model development, a model termed the hybrid grid model was recommended for modeling of both horizontally and vertically framed miter gates (Commander et al. 1992b). This model incorporates a unique beam element that includes eccentricity of the member neutral axis with respect to any reference plane (Chapter 3). In this report, the hybrid grid model is referred to simply as the grid model.

A major task of this project is to perform field testing and subsequent analytical evaluation on three operational miter lock gates. The purpose of this task is to evaluate the field testing system (verify that field testing can be performed efficiently and reliably) and to verify the analytical modeling procedures that are developed. The first of the three field studies was performed on a leaf of the lower horizontally framed miter gate at the John Hollis Bankhead Lock and Dam located on the Black Warrior River near Birmingham, AL (Commander et al. 1992b). The second of the three tests was performed on a vertically framed miter gate of the Emsworth Lock and Dam located on the Ohio River near Emsworth, PA. The third field test has been conducted for a horizontally framed miter gate at the Red River Lock and Dam No. 1, located near Alexandria, LA.

This report describes the analytical and experimental field studies that were conducted at the Emsworth Lock and Dam. The main lock chamber at Emsworth Lock and Dam is 110 ft wide and 600 ft long with vertically framed miter gates located at both ends. The lock was opened in 1921; however, the original miter gates were replaced in 1982. The Emsworth site was selected for testing since the gates are vertically framed (the previous test was performed on a horizontally framed miter gate) and are relatively new. The gates

have not experienced any significant damage. A structurally sound gate is desirable for testing since the primary goal of the testing is to evaluate the modeling and analysis procedures. A more reliable evaluation is possible when a minimum of unknown quantities (effects of damage or deterioration) is present.

Chapter 2 describes the experimental testing and some interesting conclusions that were determined during the field study. In Chapter 3, the modeling procedures and analysis are described, and a detailed examination of the correlation between the field and analytical data is presented. Chapter 4 provides general conclusions of this study. Appendixes A through E present strain history graphs that compare the measured and computed results.

## 2 Field Testing

---

On April 27, 1992, the landside leaf of the downstream (lower) gate in the main lock chamber was monitored during field testing to measure the inservice structural behavior. Due to geometric symmetry of a miter gate about the center of the lock, it is assumed that the structural response of each leaf is symmetric; therefore, only one gate leaf was tested. This assumption was verified during previous field tests (Chasten and Ruf 1991), and due to the good condition of this gate, the assumption of symmetry about the lock center line was considered appropriate. Each leaf of the lower gate is approximately 38.5 ft in height, and spans 58 ft between the center lines of the end girders (miter and quoin girders). Both leafs are divided into two panels by a vertical girder located at the center of the leaf. Each panel includes five equally spaced vertical beams and a set of diagonal members located on the downstream face of the leaf. The general configuration of the landside leaf of the lower miter gate is shown in Figure 1 and a photograph showing a view of the miter gate from downstream is shown in Figure 2.

### Loading and Instrumentation

Experimental monitoring was performed for two loading conditions:

- a. Hydrostatic head differential load. With the gate in the mitered position, head differential loads were applied by raising the lock chamber water elevation from the lower pool elevation to the upper pool elevation.
- b. Gate operating load. With the lock chamber water elevation at the lower pool elevation (zero head differential), the leaf was swung opened and closed. Loads applied to the leaf were the force of the operating strut and the inertial resistance of water on the submerged portion of the leaf.

Two tests were conducted for each loading condition.

Instrumentation consisted of steel strain transducers with an effective gage length of 3 in., a data acquisition system (DAS) that records data at a

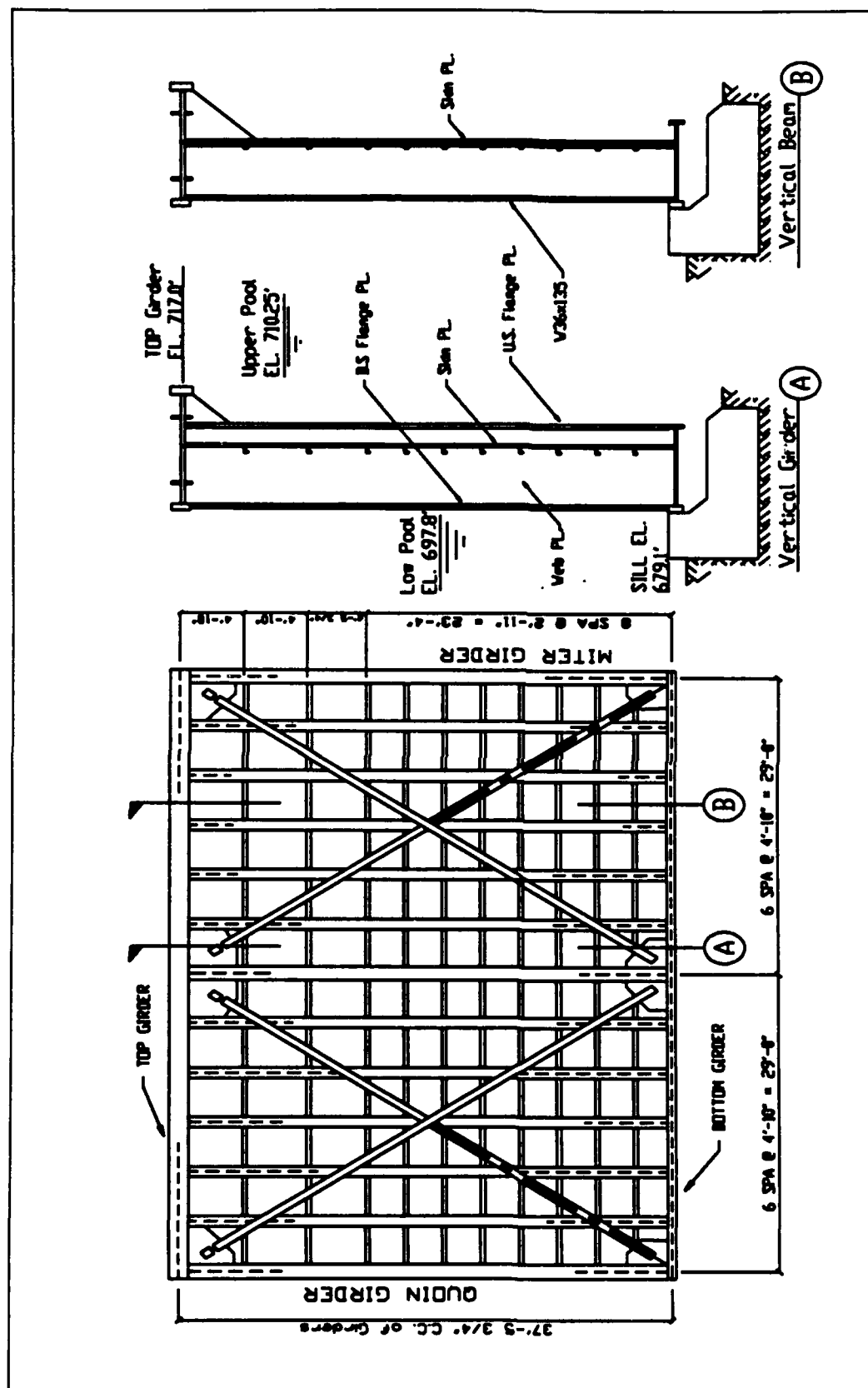


Figure 1. Landside leaf of the lower gate: downstream elevation

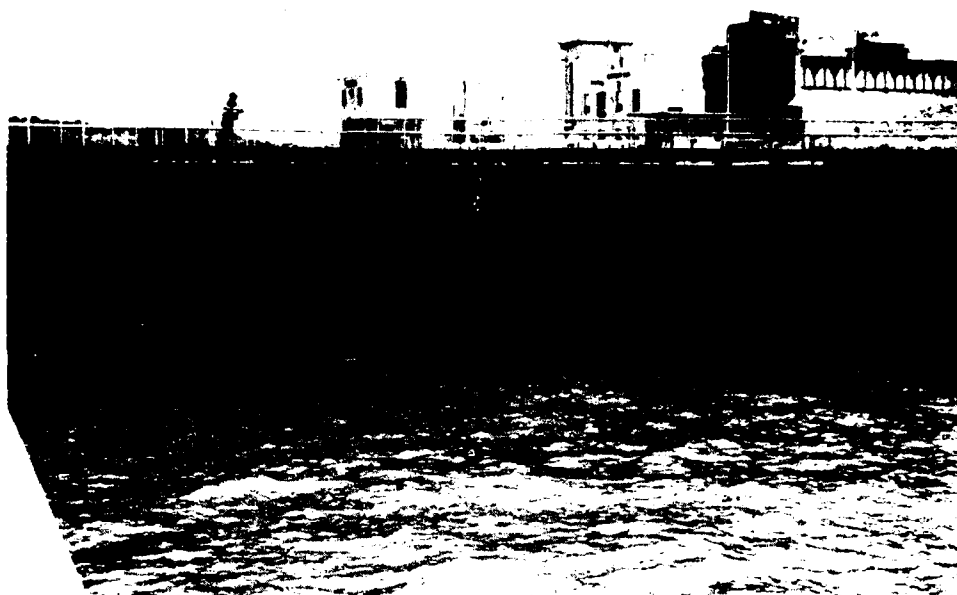


Figure 2. Photograph of miter gate from downstream

frequency of 32 Hz, electrical cables (to connect the transducers and DAS), and a position indicator. Thirty-two transducers were bolted or clamped to various structural members and were oriented parallel to the length of those members, since measurement of axial and flexural behavior were of primary interest. The transducer locations, numbered by their corresponding DAS channel numbers, are shown in Figure 3 and Figure 4. A downstream view of the instrumented landside leaf is shown in Figure 5. The location of transducers was identical for both load conditions with the exception that the transducers for DAS channels 31 and 32 were located on an intercostal angle for the head differential tests, and on the operating strut for the gate operation tests. With a two-man crew, instrumentation and testing of the gate leaf took less than 8 hr, and impact on lock traffic was minimal. Access to the gate leaf was from a work flat supplied by the lock operating personnel.

### Head differential tests

The two head differential tests consisted of monitoring strain (measured by the 32 transducers) as the water level in the lock chamber was raised from lower pool elevation to upper pool elevation. The maximum pool differential (lift) at Emsworth Lock and Dam is approximately 18 ft; however, at the time of the field test, the lift was approximately 12.5 ft (upper pool elevation was 710.25 ft and lower pool elevation was 697.8 ft as shown in Figure 1). For each test, the datum for strain measurement was established by setting all of the strain readings to zero (balancing), while the gate was mitered and the chamber pool level was at the lower pool elevation (zero head differential). Strains were monitored and recorded continuously as the lock chamber was filled. The position indicator was activated at 20-in. intervals of increasing chamber pool level. When the position indicator was activated, a mark was

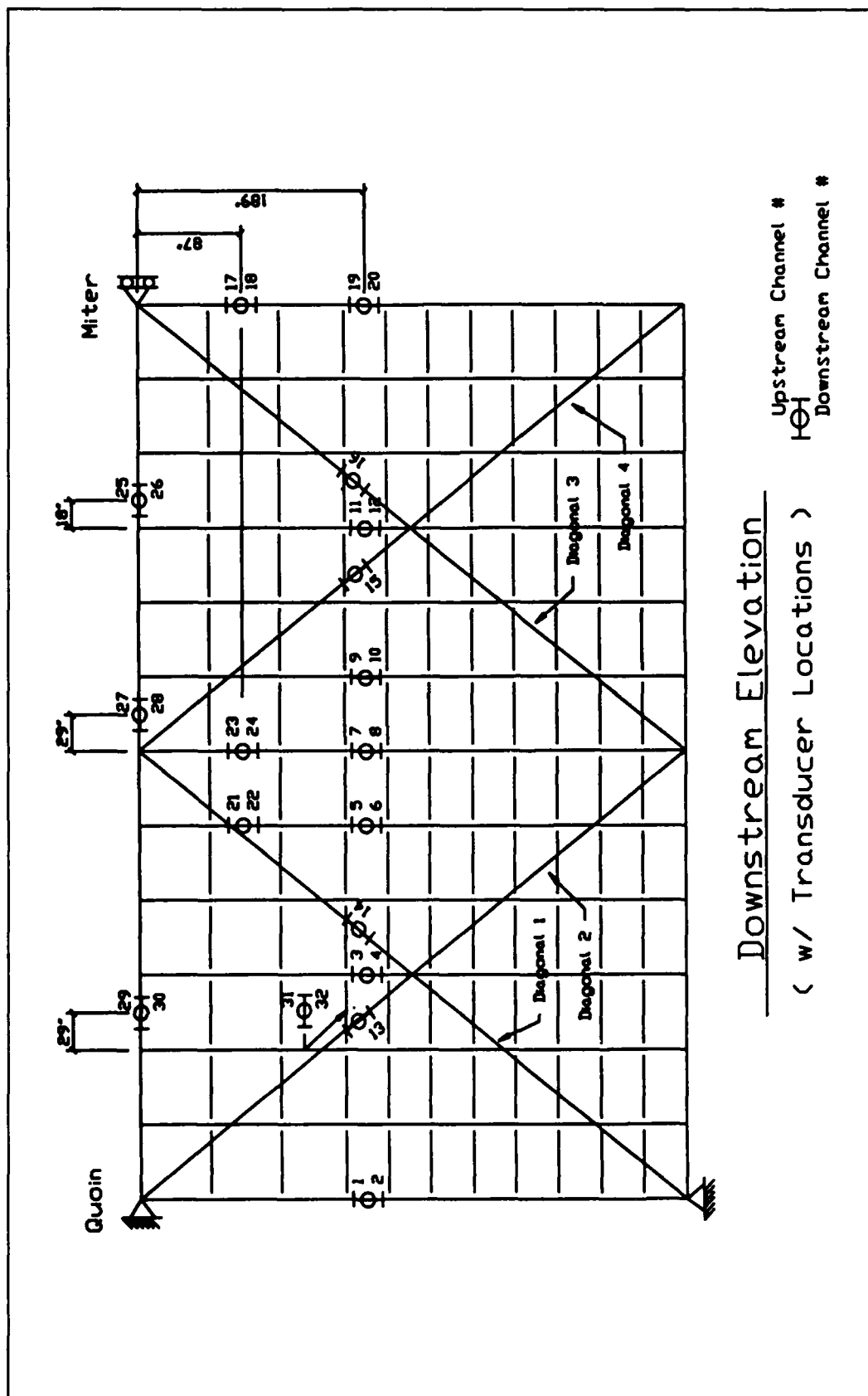


Figure 3. Downstream elevation of gate leaf with transducer locations

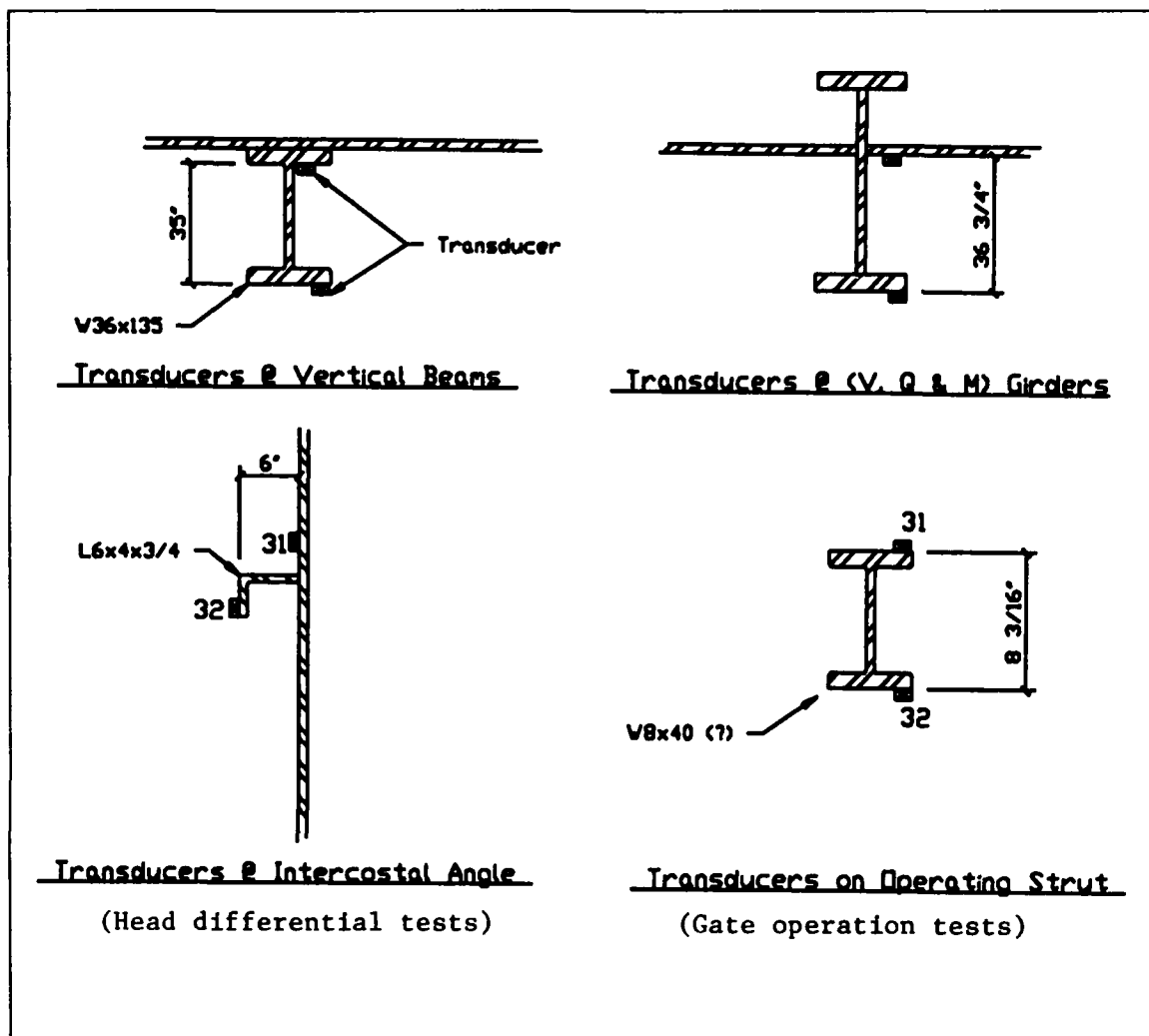


Figure 4. Cross sections with transducer placement

recorded by the DAS along with the strain data. This was done so that the strain data could be correlated with head differential and time.

The time required to fill the lock chamber was slightly greater than the maximum recording time that is limited to approximately 6 min (with 32 channels) due to the capacity of the DAS. Therefore, to assure that the maximum strains were recorded (i.e. chamber full), monitoring of strain data began when the chamber pool was approximately 10 in. above the lower pool level. Although the strain history was not monitored for the first 10 in. of head differential, the total strain was measured with respect to the datum (set at zero head differential). After the head differential tests, two transducers (Channels 31 and 32) were removed from the intercostal location and mounted on the operating strut so the behavior of the strut could be monitored during the gate operation tests.



Figure 5. Downstream view of instrumented miter gate leaf

After testing, the data were reviewed, and at various transducer locations, an unusually large magnitude of strain was produced during the initial 10 in. of head differential. This was not known at the time of testing, so no attempt was made to monitor strains for the first 10 in. of chamber fill. Reasons for the large magnitude of strain is discussed in Field Test Conclusions on page 9.

### Gate operation tests

The two gate operation tests (opening and closing) consisted of monitoring strains as the leaf was operated (opened or closed) under zero head differential. For the gate opening test, the datum for strain readings was established by balancing the transducers while the gate was locked in the miter position. Recording of data began just prior to gate operation and continued until the gate leaf was in the open (recess) position. The second gate operation test was performed in the same manner, except that it started with the gate leaf in the recess position and ended in the closed (mitered) position.

After the first operation test, strain data were checked to ensure that the system was operating properly and to identify any irregular signals. It was observed that the strain level on diagonal 4 (Figure 3, channel 15) remained zero throughout the test. Under gate operation, the leafs are subject to torsion, induced by the twisting action of the operating strut force and resistance of water on the submerged portion of the leaf. Since the diagonals provide the majority of torsional resistance for the leaf, significant strains should occur in the diagonals during gate operation. Therefore, it was suspected that a problem existed in either the testing system or the gate leaf. The transducer on



diagonal 4 was checked and determined to be attached properly and in working order; therefore the possibility of system error was remote. A brief inspection of the structure revealed that diagonal 4 was slack.

Appropriate staff members were informed of the situation and a diver has since been employed to inspect the submerged portion of the diagonal for damage. The inspection indicated that the diagonal was loose; however, no other problems were found in the diagonal member or its connection. No speculation was made as to why the diagonal was loose.

## **Field Test Conclusions**

These results provide an excellent example of the value of field testing in the assessment of structural integrity. This miter gate is operated and observed on a daily basis, and prior to testing, visual inspections did not reveal any structural inadequacy. The detection of the loose diagonal was the direct result of a quick review of experimental measurements in the field. Since the gate leaf is operational, it is recognized that the loose diagonal may not warrant immediate corrective action. However, over an extended period of time, the operational characteristics of the gate may be affected.

Diagonals are designed to include an initial prestress that provides the torsional strength to keep the leaf plumb while it hangs under its own weight. The amount of required prestress is such that each diagonal will always remain in tension under operating conditions. The prestress may be as high as 20 ksi for diagonals fabricated of 50-ksi steel (such as those of this miter gate). Subsequent to the initial prestressing that results in a plum gate leaf position, any loss of diagonal prestress would cause the leaf to twist. Therefore, it is speculated that the gate leaf does not hang plum due to the loss of prestress in the loose diagonal. It was not possible to determine if the gate leaf was, in fact, out of plum, since the lower part of the leaf was submerged.

Diagonal 4 is attached at the top of the vertical girder and the bottom of the miter girder. The loss of diagonal tension (assuming that this diagonal was prestressed) would result in the bottom girder of the leaf to deflect in the upstream direction (away from the sill) at the miter end. (Although it was determined that diagonal 4 is loose, no measurements have been taken to verify the initial displacement of the bottom girder.) The initial displacement of the bottom girder changes the support conditions of the gate and, accordingly, affects its resulting load response.

The fact that the diagonal was loose did affect the structural performance of the gate leaf when subjected to head differential loading. For the head differential tests, unusually large magnitudes of strain were measured at various locations for the initially recorded head differential of 10 in. Larger than expected strains were measured in diagonals 1, 2, and 3 (Figure 6) and the downstream flanges of the members to which the diagonals were attached (quoins girder, miter girder, and the vertical girder; see Figure 7). For other

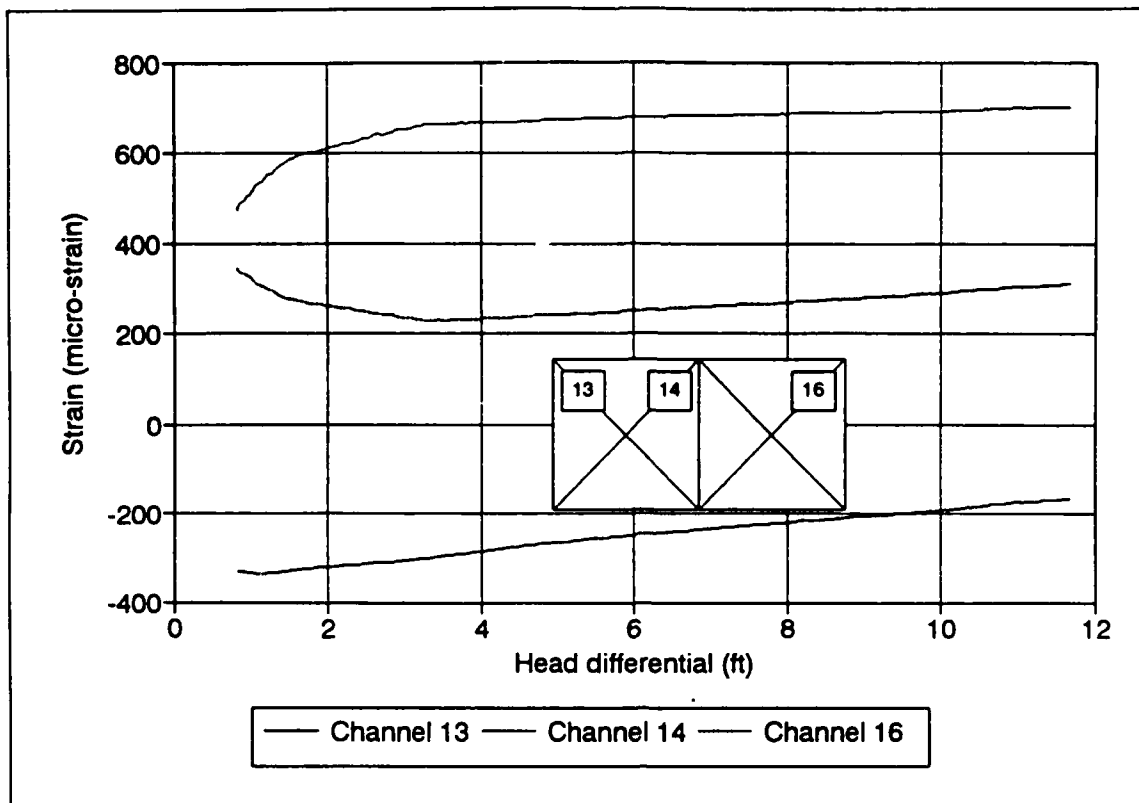


Figure 6. Large initial strain on diagonals 1, 2, and 3 (channels 14, 13 and 16, respectively)

locations, the strains measured at a head differential of 10 in. were near zero, as expected. (Appendix A shows results for all channels.) Diagonal members provide torsional rigidity and the large initial strain occurred in only the diagonals and members to which they are attached. This indicates that the gate leaf was initially being twisted (subject to torsional loading) with respect to the original (presumably out of plumb) datum position.

Additionally, for low levels of pool differential, the strain response with increasing head differential is highly nonlinear. This is attributed to the changing boundary condition along the bottom sill. As the head differential increased, the bottom girder was gradually pushed back in contact with the sill. Eventually, when the bottom girder was in contact with the sill along its entire length, the strain versus head differential response was near-linear as expected. Inspection of the strain graphs in Figure 6, Figure 7, and Appendix A indicates that the bottom girder was in contact with the sill along its length when the pool differential was approximately 20 in. (as indicated by the near-linear response for values greater than 20 in.).

In this case, the effect of the detected damage is not considered crucial since the gate operation is not inhibited. However, the maximum measured strain in diagonal 1 (channel 14 of Figure 6) was approximately 700 micro-strain (0.0007 in. per inch) that corresponds to a stress of almost 21 ksi. There

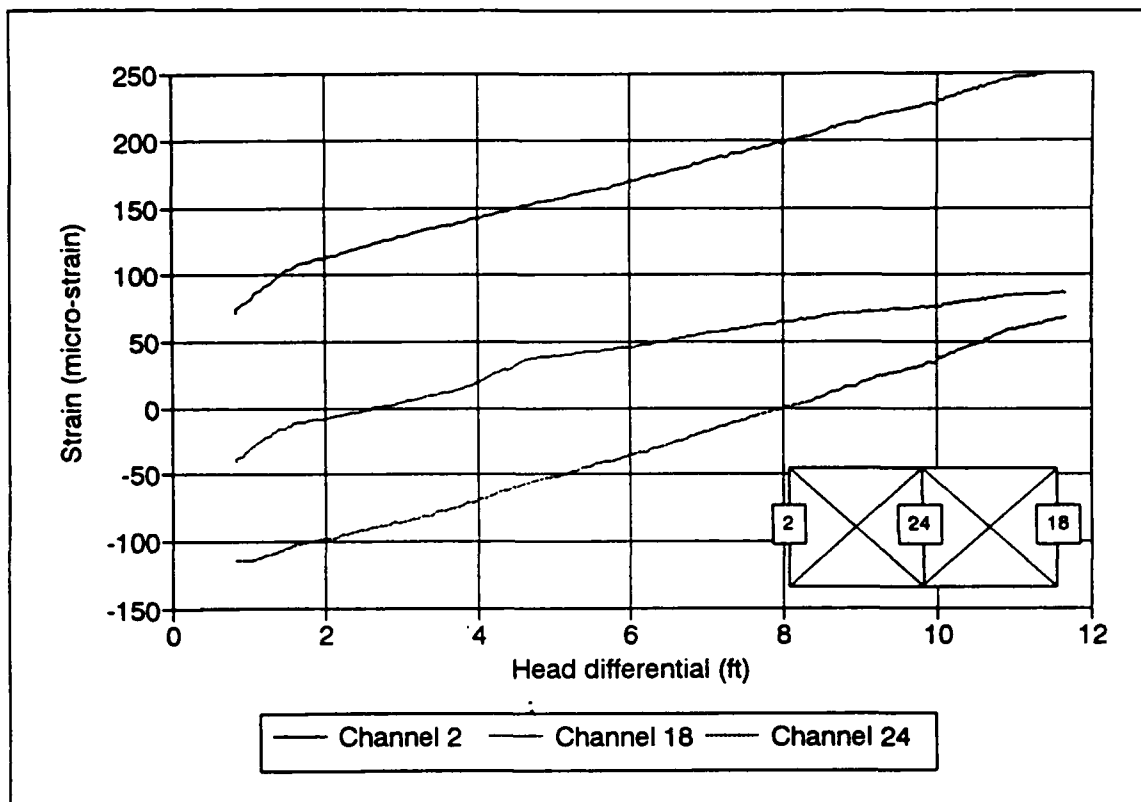


Figure 7. Large initial strain on downstream flanges of vertical girders

may be cause for concern depending on the level of prestress. If the diagonal had a prestress of 10 to 20 ksi, then the total stress in the diagonal was approximately 30 to 40 ksi. This is much higher than the intended operating stress limit of 25 ksi (for 50-ksi steel).

These conclusions are based solely on the examination of the field test results. The occurrence of zero or highly nonlinear strain responses (such as those obtained at several transducer locations during these tests) generally indicates structural damage or system malfunctions (i.e. loose or dead transducer). This can easily be detected by visual inspection of the strain history graphs. Assessing as many as 32 sets of data is time consuming and requires experience. This procedure could be simplified by developing DAS software that can check the data for these types of occurrences at the time of testing. Based on these findings, any new developments in data acquisition should incorporate such features.

### 3 Structural Analysis and Data Comparison

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For this study, a simple finite element program, Structural Analysis and Correlation (SAC), is used to perform the structural analyses. SAC was originally developed to analyze bridges (Goble, Schulz, and Commander 1990), and various features have been added to customize the program for miter gate modeling and analysis. General modeling procedures for miter gates have been developed in previous phases of this project (Commander et al. 1992a and b). A grid model incorporating plate-membrane elements and eccentric frame elements provided an accurate representation of a horizontally framed miter gate (Commander et al. 1992b) and is considered to be well suited for representing vertically framed miter gates.

SAC has several element types including a plate-membrane element and an eccentric frame element. The plate-membrane elements in SAC consist of a combination of a constant energy quadrilateral element and a rectangular Kirchhoff plate element. The plate-membrane element provides resistance to five degrees of freedom (DOF) per node: membrane forces along two in-plane axes, an out-of-plane force normal to the plate, and two bending moments about the two in-plane axes. In the grid model, these elements are used to represent the skin plate. For more complex representations, the plate-membrane elements can be used to model girder and diaphragm webs as well as the skin plate, but that was not done for the Emsworth analyses.

Eccentric frame elements are space frame elements for which the flexural neutral axis (NA) (centroidal axis) is eccentric to the end nodal points. This enables the frame elements to be spatially defined by nodal points that lie in a plane other than the member NA. Use of these elements greatly simplifies the model generation procedure for two-dimensional (2-D) analysis of miter gates. For example, the skin plate and flexural NA of supporting girders do not lie in the same plane. However, plate-membrane elements that represent the skin plate and eccentric frame elements that represent the supporting members may be defined by a single plane. The location of the flexural NA of frame elements with respect to the plate elements may be simply defined by the eccentricity (this has the same effect as rigid extensions). Definition of additional rigid elements and nodes is not required, so model generation remains simple enough for routine procedures.

## Model Description

The landside gate leaf was modeled as a grid of eccentric frame elements and rectangular plate-membrane elements. The model geometry is defined in a 3-D cartesian coordinate system. The Y-axis is vertical and is located at the quoin end of the leaf. The X-axis is parallel to the top and bottom girders and is located at the elevation of the bottom girder web. The Z-axis is perpendicular to top and bottom girders so that depth or thickness of the gate leaf is measured along the Z-axis. The reference plane (X-Y plane), at which Z equals zero, is located to include the work line of the top girder. The work line, is defined by EM 1110-2-2703 (Headquarters, Department of the Army 1984) as an imaginary line that extends between the quoin and miter contact points of the top girder.

A computer-generated display of the model is shown by Figure 8. The grid model is defined in three planar segments. The center segment defines the portion of the leaf between the outermost vertical beams, and the two outer segments define the portions of the leaf between the outermost vertical beams and the quoin and miter girders. The nodes for the center segment have Z-coordinates located at the center of the skin plate (relative to the reference plane) and X and Y coordinates located at the intersections of the vertical members and the intercostals. Nodes defining the quoin and miter girders lie in the reference plane (corresponding to the contact points of the top girder), with X coordinates located at zero (quoin girder) and 58 ft (miter girder), and Y coordinates located at the intercostal elevations. Additional nodes joined to the top and bottom nodes of the vertical girders with rigid links are defined to attach the diagonal members.

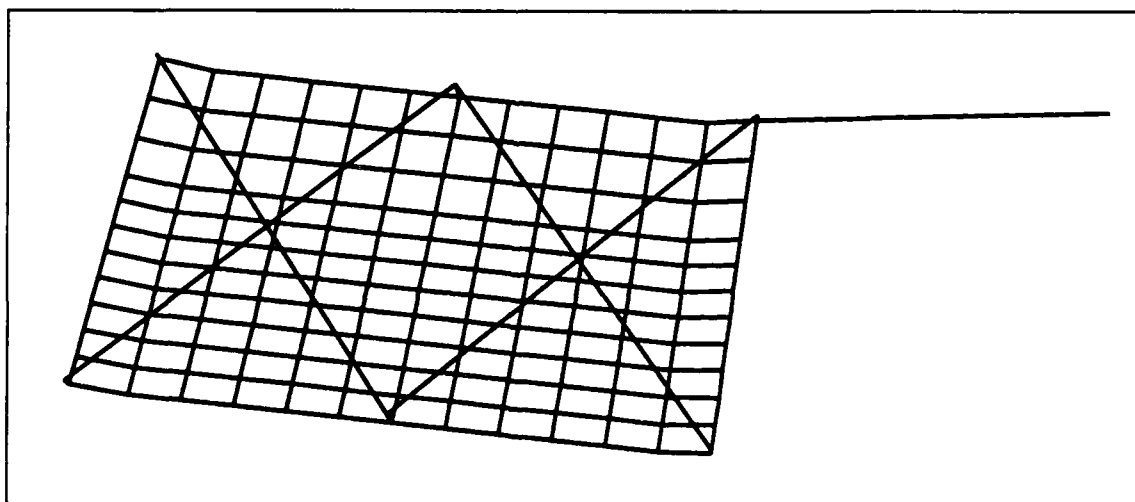


Figure 8. Display of gate leaf finite element model

The skin plate is represented by plate-membrane elements having the thickness of the skin-plate. Eccentric frame elements with actual member cross-sectional properties simulated the top and bottom girders, vertical beams and girders, diagonals and intercostal angles. The properties for each member were computed with respect to the member flexural NA. Each eccentric frame element was assigned an eccentricity in the Z-direction equal to the distance between the actual location of the flexural NA of the member and its end nodes. A plan cross section showing the eccentricity of the frame elements is shown in Figure 9.

Boundary conditions for the leaf are defined by restraining nodal DOF. Nodal DOF's for displacement in the X, Y and Z directions are restrained for the nodes at the quoin end of the model, nodes of the bottom girder are restrained in the Z-direction to represent restraint of the bottom sill, and the node representing the miter contact of the top girder is restrained to motion in the upstream-downstream direction along the lock center line.

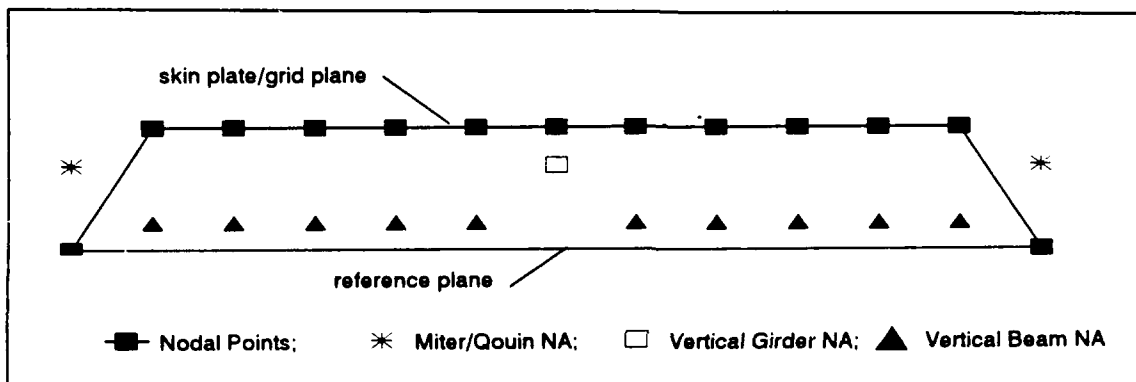


Figure 9. Gate leaf model plan cross section

## Data Comparison

To verify or check the analytical model, comparison of analytical and experimental data is required. The only response mechanism used for data comparison in this study is strain; however, several means of comparison are utilized. Data were compared using a graphical approach and various numerical comparison quantities as described in the following paragraphs.

### Graphical approach

Graphical comparisons provide an excellent intuitive perspective of structural behavior. In this study, strain history plots that show strain as a function of head differential were used to compare experimental strains and analytical results computed for discrete levels of head differential. Results from transducer locations at common cross sections were generally presented in the same

graph so that axial and bending responses could be conceptually evaluated (see Appendixes A through C).

### Absolute error

The absolute error  $E_{abs}$  provides a simple measure of model accuracy that is most useful in comparing one model to another. The difference in analytical and experimental strain is computed at each transducer location for every load case considered. The absolute error is the sum of the absolute values of the differences.

$$E_{abs} = \sum_{i=1}^n |\epsilon_{f_i} - \epsilon_{c_i}| \quad (1)$$

where

- $\epsilon_{f_i}$  = Field strain measurement of a single transducer for a given head differential load
- $\epsilon_{c_i}$  = Computed strain corresponding to  $\epsilon_{f_i}$
- $n$  = The number of transducers times the number of applied load cases (total number of different strain readings)

To compare results with different values of  $n$ , a useful quantity is the average transducer error  $E_{ave}$ .  $E_{ave}$  is simply  $E_{abs}$  divided by  $n$ .

### Percent error

The percent error  $E_{per}$  provides a better conceptual evaluation of a model than the absolute error. The summation of the differences (between analytical and experimental results) squared is divided by the summation of the field strains squared. The percentage error is computed by the following equation:

$$E_{per} = \frac{\sum_{i=1}^n (\epsilon_{f_i} - \epsilon_{c_i})^2}{\sum_{i=1}^n \epsilon_{f_i}^2} \times 100 \quad (2)$$

The terms of Equation 2 are squared so they are always positive and strain values with the larger magnitudes have a larger effect on the error term.

## Correlation factor

The correlation factor ( $CF$ ) is a measure of how strongly two variables are linearly related. The  $CF$  can range from -1.0 to 1.0. A  $CF$  of 1.0 indicates that there is a perfect linear correlation between the two variables in a positive sense (as one variable increases, the other increases). A perfectly opposite correlation (as one variable increases, the other decreases) would result in a  $CF$  of -1.0. If the variables are uncorrelated (there is no linear relationship between the two sets of data), a  $CF$  of 0.0 is obtained. The  $CF$  is useful in comparing analytical and experimental (field) data. The  $CF$  provides a measure of how closely the shape of the experimental and analytical strain-versus-head differential curves match. For a good model, the analytical and experimental data should be linearly related in a positive sense (the  $CF$  should be approximately equal to 1.0). The  $CF$  is computed using the following equation:

$$CF = \frac{\frac{1}{n} \sum_{i=1}^n (\epsilon_{fi} - \bar{\epsilon}_f)(\epsilon_{ci} - \bar{\epsilon}_c)}{\sigma_{\epsilon f} \sigma_{\epsilon c}} \quad (3)$$

where

$\epsilon_{fi}$ ,  $\epsilon_{ci}$ , and  $n$  are as described above

$\bar{\epsilon}_f$  = Mean value of the measured strains

$\bar{\epsilon}_c$  = Mean value of the computed strains

$\sigma_{\epsilon f}$  = Sample standard deviation of the measured strains

$\sigma_{\epsilon c}$  = Sample standard deviation of the computed strains

The error functions were computed for the overall structural response and for the individual transducer locations as well. Therefore, it could be determined at which locations on the structure a good agreement between the computed and measured results was obtained and where there were poor correlations.

## Analysis Results

Analyses that simulated the head differential tests were performed for hydrostatic loading at 20-in. intervals of head differential so that strain histories could be computed. The tests for gate opening and closing were not simulated since an accurate model of loading produced by gate leaf movement through water is not well defined. As discussed in Chapter 2, the variation of measured strain as a function of head differential was highly nonlinear for approximately the initial 20 in. of head differential and was near-linear for



subsequent levels. Theoretically, this response is near-linear for any variation in head differential if the structure remains linear elastic and geometrically linear (has constant support conditions). Due to the low level of applied loading, inelastic behavior is not a consideration. The nonlinear response that was measured in the head differential tests is attributed to changing support conditions between the bottom girder and the sill as the head differential was increased. The analytical model is a linear elastic model, and no attempt was made to simulate the variation in support conditions along the bottom girder.

Although highly nonlinear responses were measured, the linear analysis results were compared with the raw data obtained from the first head differential test. This was done to gain insight on the structural behavior. As expected, very poor correlations between the measured and computed results were obtained for results at locations on the diagonals and the downstream flanges of the vertical girders to which the diagonals are connected (strain channels 2, 13 through 16, 18, and 24). Conversely, reasonable correlations were obtained at locations on members not directly connected to the diagonals. When a gate leaf is subjected to torsion, the only members that are significantly affected are the diagonal members and the members to which they are attached. These observations lead to the conclusion that a large amount of twisting (or in this case straightening) of the leaf was induced as the pool level in the lock chamber began to rise. Strain history graphs illustrating this phenomena are presented in Figures 6 and 7 and Appendix A. The graphs in Appendix A indicate that for head differential greater than 20 in., the measured strain response curves are nearly linear and match the shape of the computed response curves rather well. For head differential greater than about 60 in., this was even more apparent.

Since no attempt was made to simulate the variation in support conditions (linear analysis), and it was desirable to verify the analysis procedures for modeling vertically framed miter gates, the analytical data were compared to results for the near-linear portions of the head differential test. This was done by assuming that the lower pool elevation was increased by 20 in. For the measured response, a 20-in. increase in low pool elevation may be simulated by defining the datum to be 20 in. of head differential. For each transducer location, the measured strain values corresponding to 20 in. of head differential were subtracted from the remaining field data. With the majority of the nonlinear data eliminated, a reasonable agreement between the measured and computed strains was obtained. Strain responses from a few data channels still exhibited nonlinear characteristics in the remaining data, so this procedure was repeated, effectively raising the lower pool level by a total of 60 in. Data comparisons from this trial produced excellent correlations. Table 1 lists the numeric evaluations of the model compared to the initial raw data, the data obtained by elimination of 20 in. of head differential, and the data obtained by elimination of 60 in. of head differential (these results are based on comparisons for 30 transducer locations, channels 1-30). These results along with the graphical results presented in Appendixes B and C indicate that this computer model is a valid representation for the Emsworth miter gate.

**Table 1**  
**Comparison of Measured and Computed Data for Various Simulations of**  
**Lower Pool Level**

<b>Data Eliminated (in.)</b>	<b><math>E_{abs}</math> (Eq. 1) (<math>\mu\epsilon</math>)</b>	<b><math>E_{per}</math> (Eq. 2)</b>	<b><math>CF</math> (Eq. 3)</b>	<b>Number of Load Cases</b>	<b><math>E_{ave}</math> (<math>\mu\epsilon</math>)</b>
0 (App. A)	12.784	66.0	0.586	7	60.9
20 (App. B)	2.865	7.0	0.965	6	15.9
60 (App. C)	994	2.8	0.986	4	8.3

## 4 Conclusions

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Although no attempt was made to simulate the changing support conditions to represent the nonlinear responses measured while filling the lock chamber, the modeling procedures proved to be beneficial in two aspects. First, the comparison of the analytical and measured responses was extremely helpful in understanding the load transfer phenomena that occurred in the field. Second, when only the portion of the head differential test that produced linear responses was considered (presumably after the bottom girder was in full contact with the sill), an excellent correlation of experimental and analytical data was obtained. Thus, it is determined that the analysis procedures developed thus far are sufficient for modeling vertically framed miter gates. Although a valid analysis comparison was obtained for the majority of the head differential test, a subsequent field test and evaluation on the structure after the diagonal is retensioned would further verify the model. Another visual inspection should be made to verify the conclusions made regarding the initial gate leaf twist.

The primary goal of this project is to develop a system that combines field testing and analytic computer methods for the purpose of evaluating structural performance. This particular study provided a unique situation in which the value of such a system was demonstrated. A structural deficiency was detected as a direct result of a quick review of field data. Furthermore, the effect of the deficiency could be assessed through examination of the field data and comparison with analytical results. Fortunately, in this case the problem of the loose diagonal is not of paramount importance and can be easily remedied.

Considering this and a previous study (Commander et al. 1992b), the analysis and modeling techniques have been sufficiently accurate for representing the effects of hydrostatic loads due to head differential. However, analytical modeling of gate operation loads has not been conducted. When a gate leaf is opened or closed, some torsional loading is applied to the gate leaf; however, the magnitude and distribution of the loading is unknown. If a numerical model that fully represents the gate leaf for all loading conditions is to be developed, torsional stiffness characteristics and specific loading should be determined. Torsional stiffness characteristics of miter gates are provided in Chapter 3 of EM 1110-2-2703 (Headquarters, Department of the Army 1984). This information should be verified experimentally by application of loading that is easily represented analytically (i.e. application of a point load at the top

of a leaf with the leaf held in place at the bottom). By incorporating accurate torsional stiffness characteristics into the current analytical models, the torsional loading might be determined by a trial-and-error approach. Various load distributions could be applied to the analytical model and results compared to the existing field data until a reasonable comparison is reached. For completeness, results for the gate opening and closing operation tests are presented in Appendixes D and E, respectively.

# References

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Chasten, C. P., and Ruf, T. (1991). "Miter Gate Barge Impact Testing, Locks and Dam 26, Mississippi River," *Proceedings of the 1991 Corps of Engineers Structural Engineering Conference*. U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Commander, B. C., Schulz, J. X., Goble, G. G., and Chasten, C. P. (1992a). "Computer-Aided, Field-Verified, Structural Evaluation: Report 1, Development of computer Modeling Techniques for Miter Lock Gates," Technical Report ITL-92-12, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

\_\_\_\_\_. (1992b). "Computer-Aided, Field-Verified, Structural Evaluation: Report 2, Field Test and Analysis Correlation at John Hollis Bankhead Lock and Dam," Technical Report ITL-92-12, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Goble, G. G., Schulz, J. X., Commander, B. C. (1990). "Simple Load Capacity Tests for Bridges to Determine Safe Posting Levels: Final Report," submitted to the Pennsylvania Department of Transportation by the Department of Civil and Architectural Engineering, University of Colorado, Boulder, CO.

Headquarters, Department of the Army. (1984). "Engineering and Design, Lock Gates and Operating Equipment," Engineer Manual 1110-2-2703, Washington, DC.

# **Appendix A**

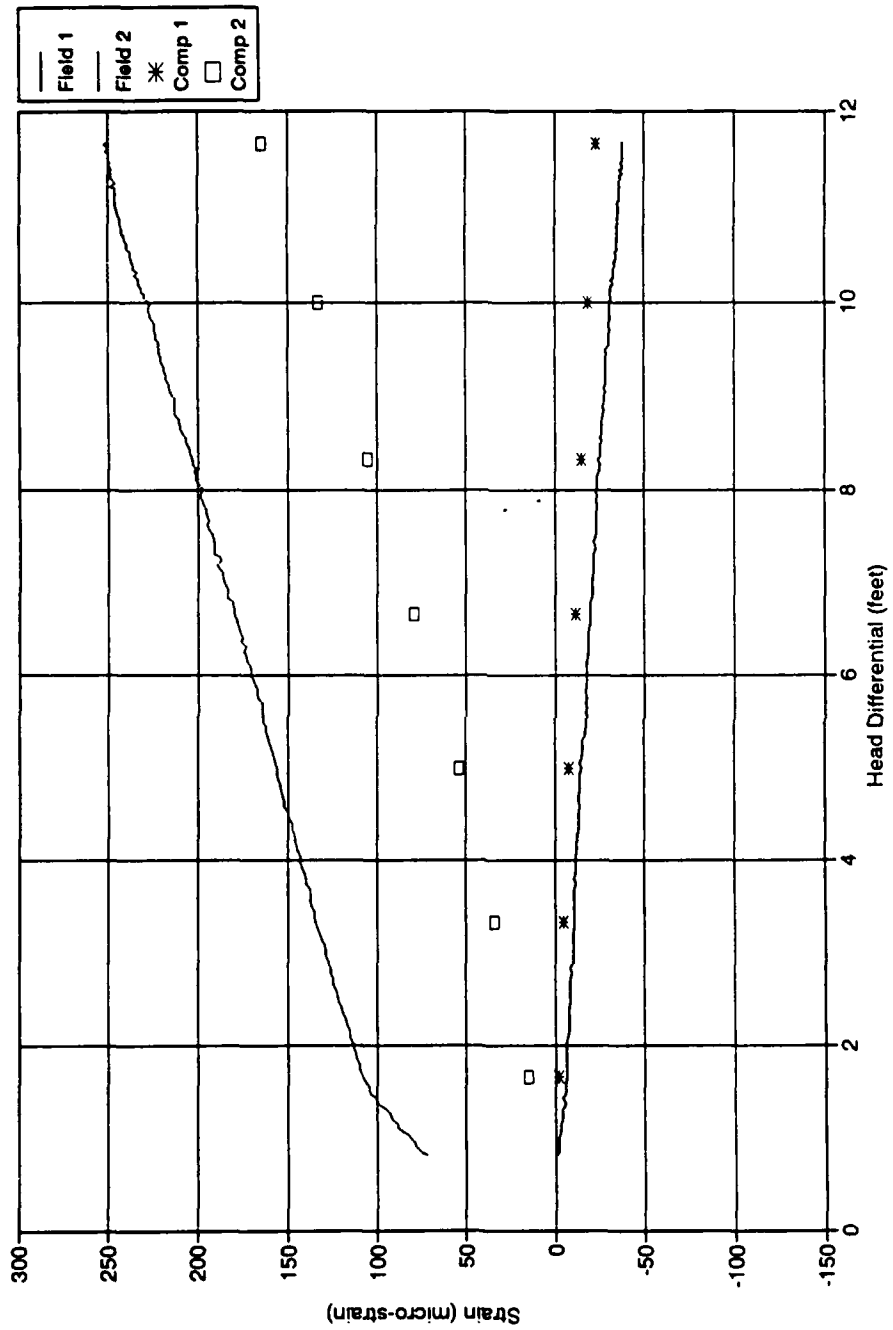
## **Strain History Comparisons**

### **(Raw Data)**

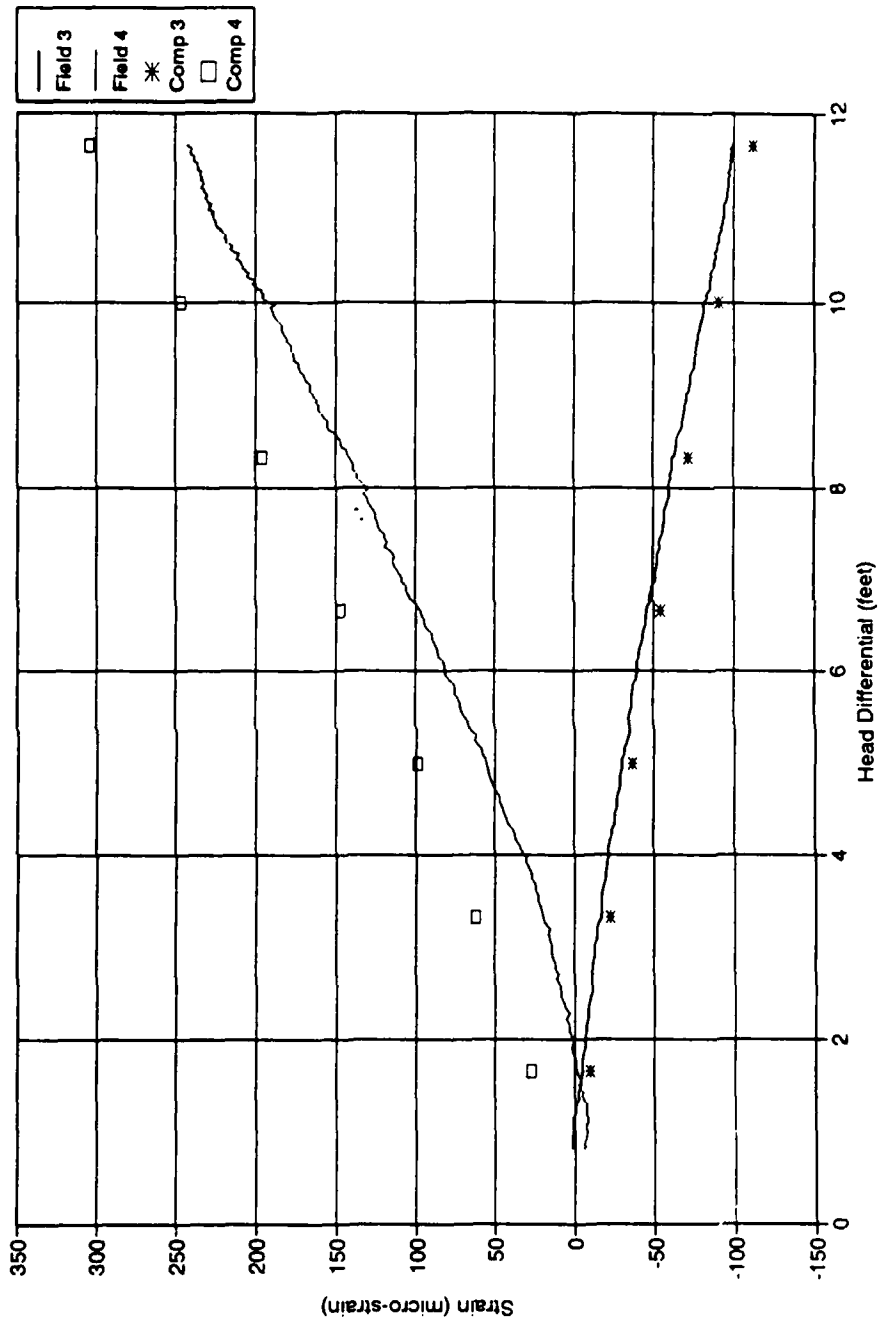
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The following graphs contain strain history as a function of head differential for analytical and raw field data. Each plot includes a legend description that identifies the transducer location by data acquisition system channel number. The term Field refers to field data and the term Comp refers to analytical data.

Emsworth: Strain vs. Head Differential  
Channels 1 & 2 - Quoin Girder

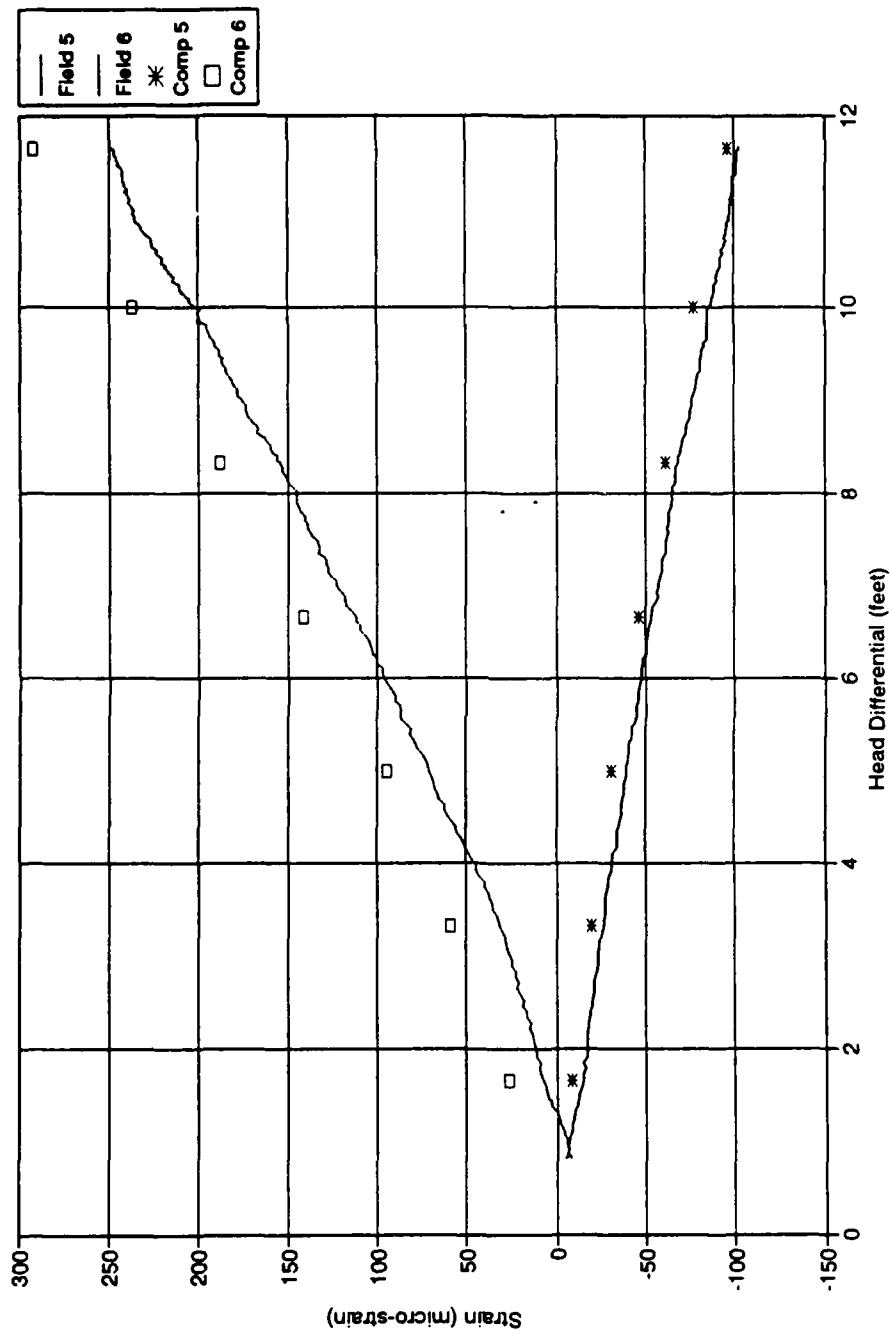


Emsworth: Strain vs. Head Differential  
Channels 3 & 4 - V. Beam 3

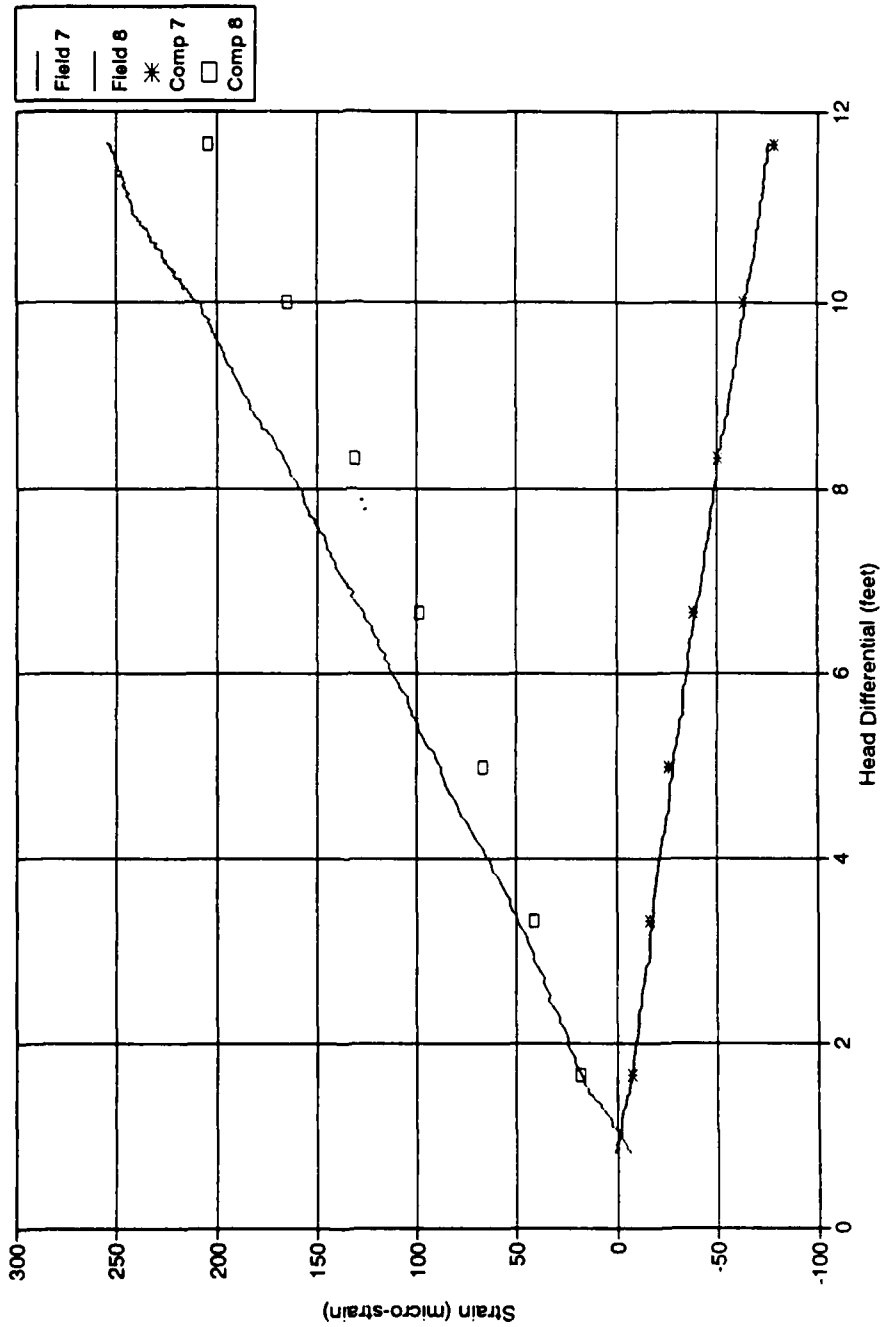




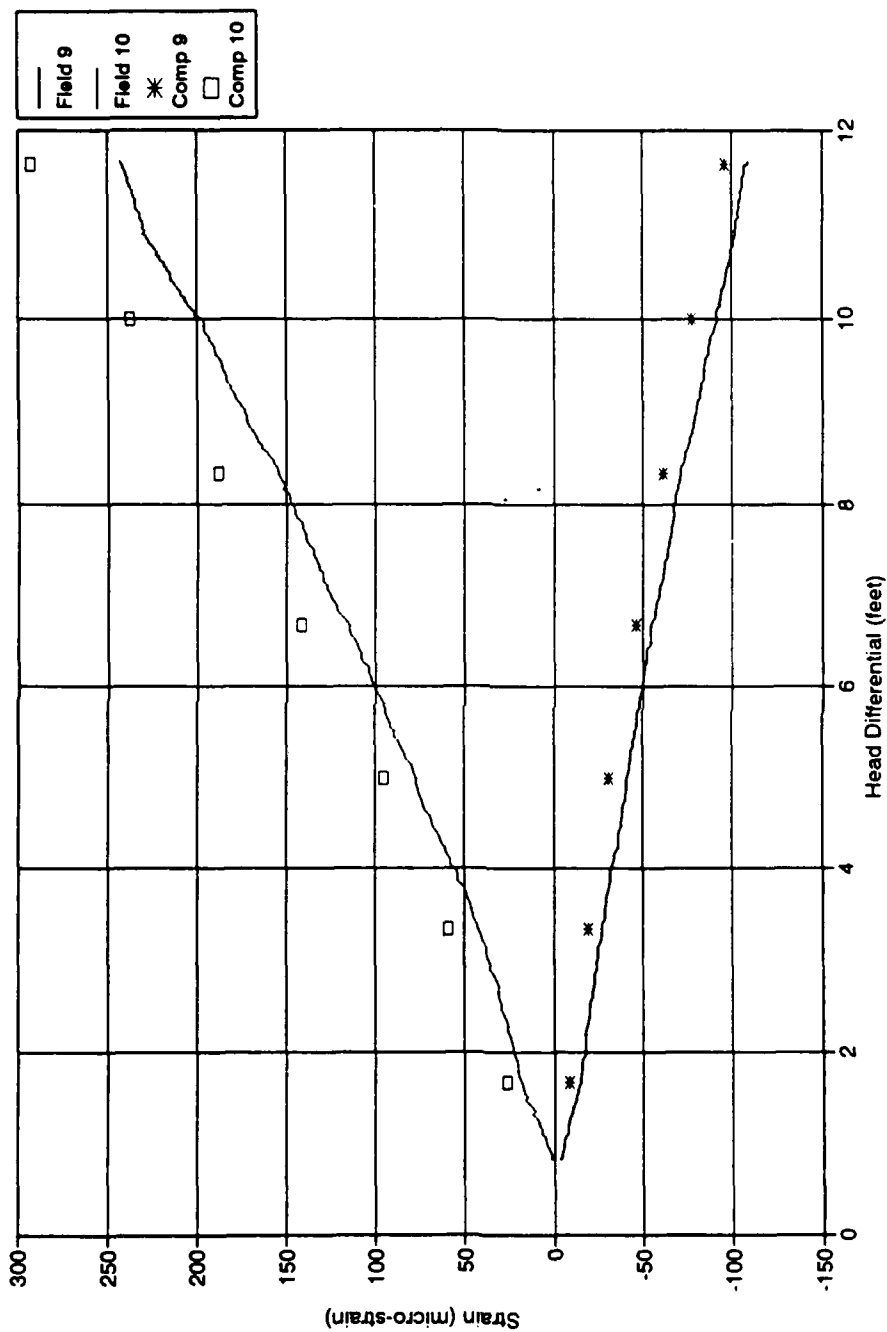
Emsworth: Strain vs. Head Differential  
Channels 5 & 6 - V. Beam 5



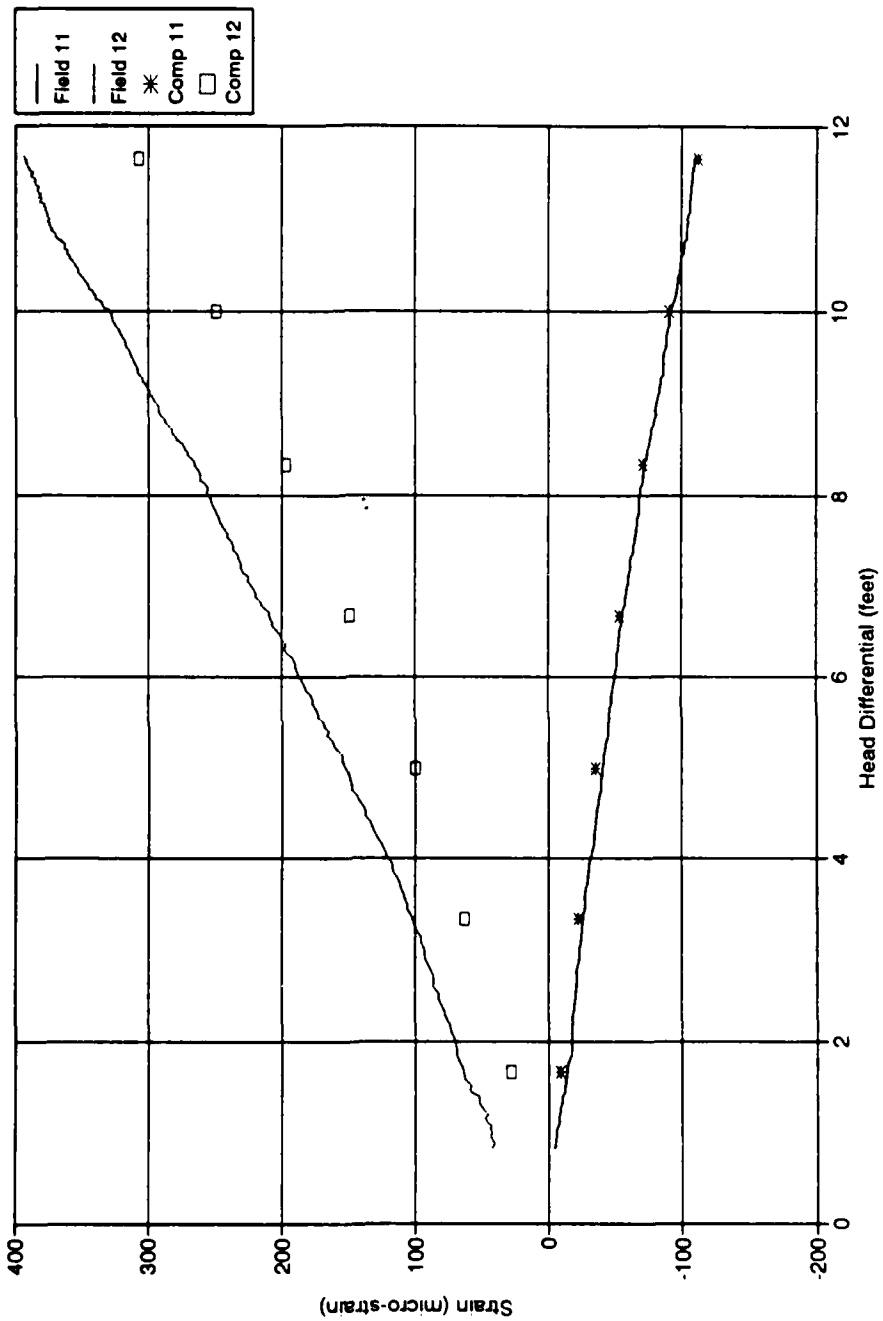
Emsworth: Strain vs. Head Differential  
Channels 7 & 8 - V. Girder (lower)

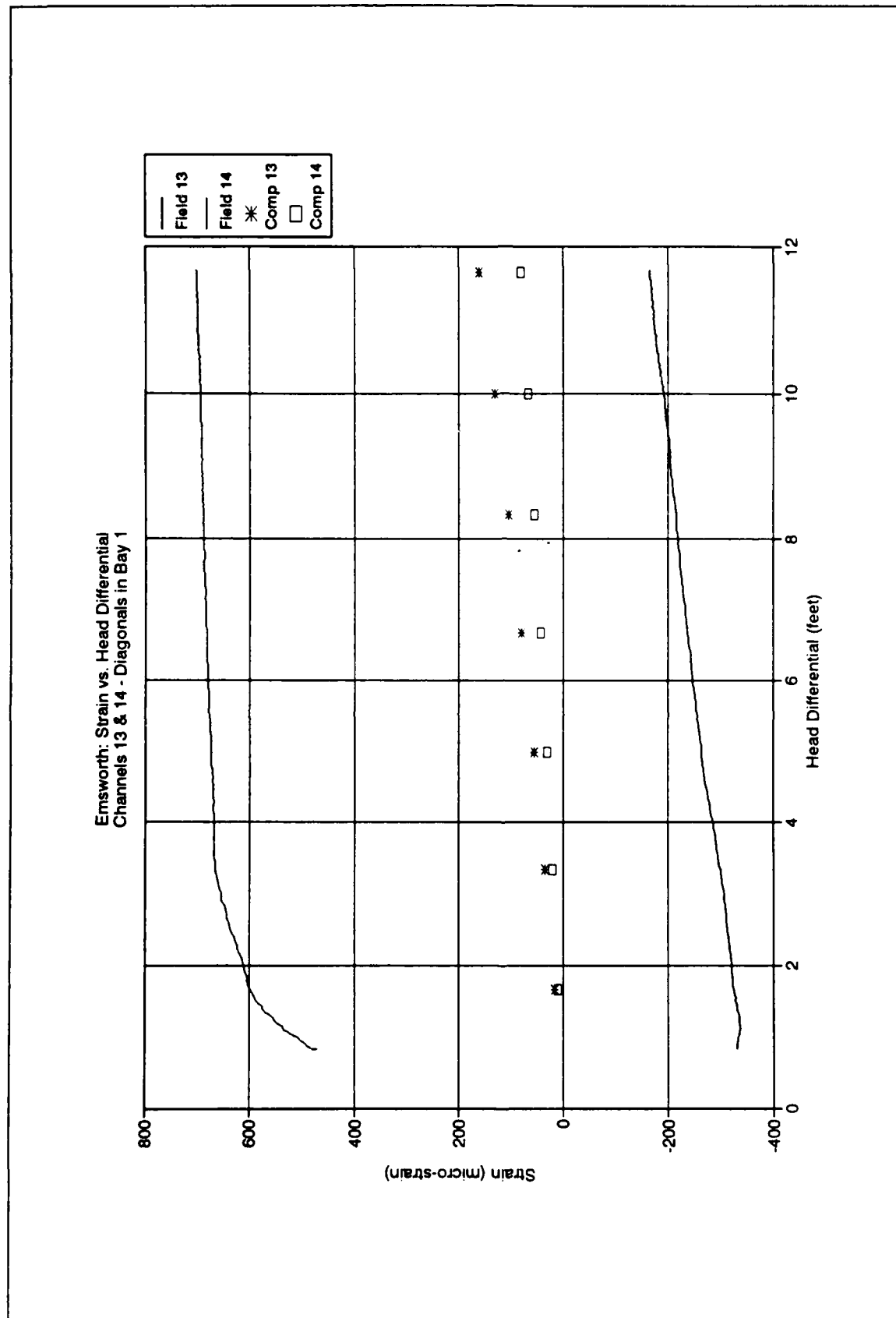


Emsworth: Strain vs. Head Differential  
Channels 9 & 10 - V. Beam 6

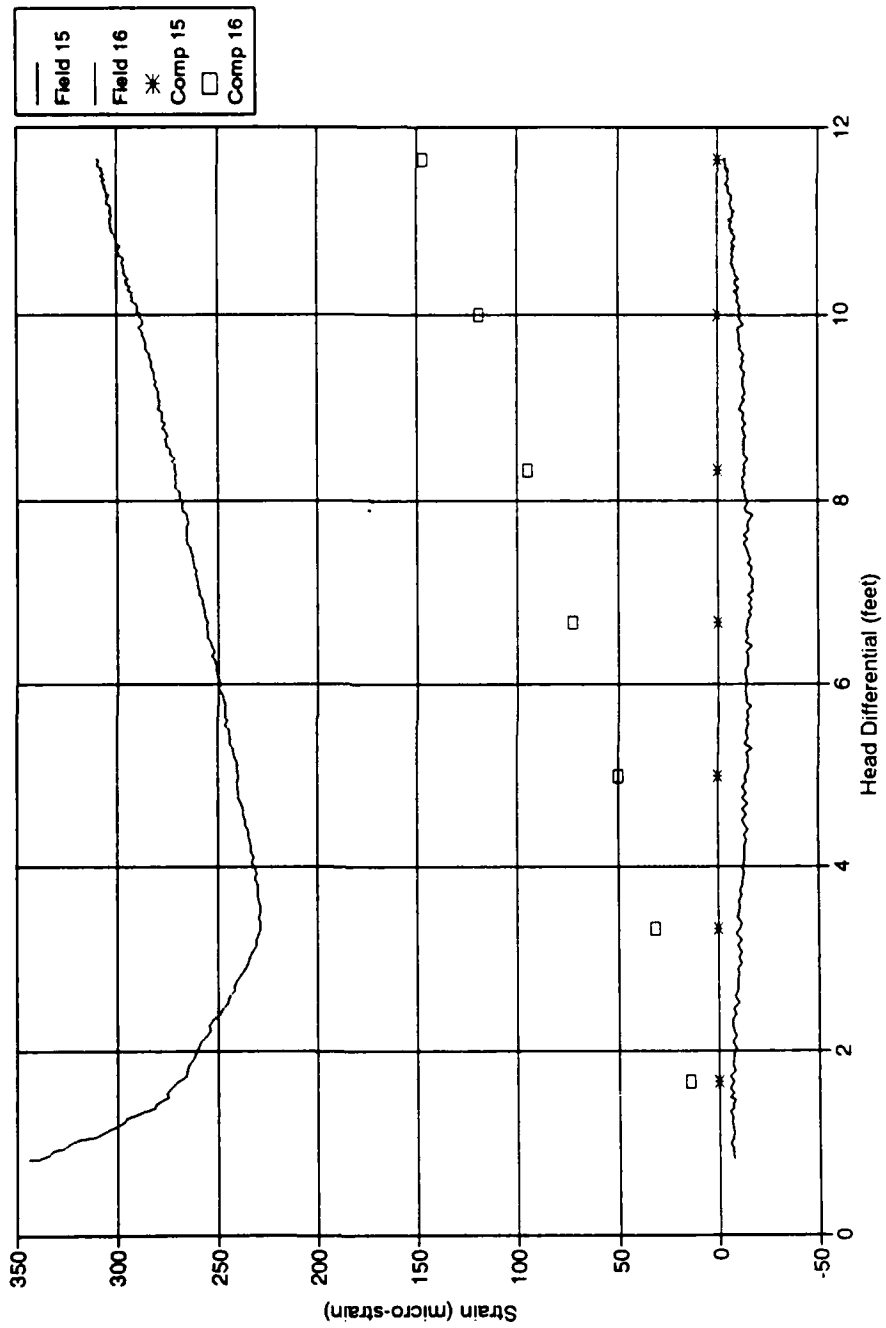


Emsworth: Strain vs. Head Differential  
Channels 11 & 12 - V. Beam 8

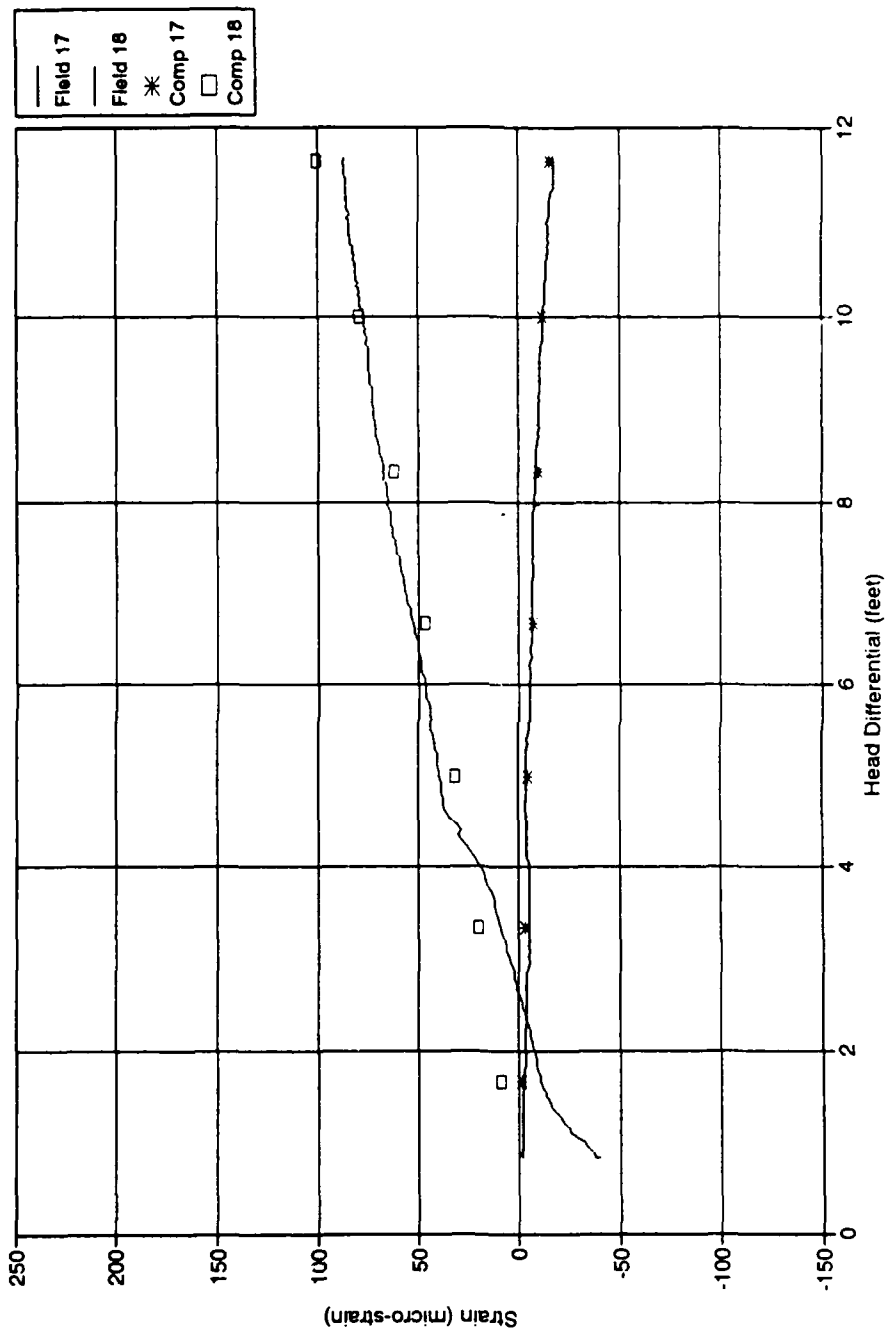




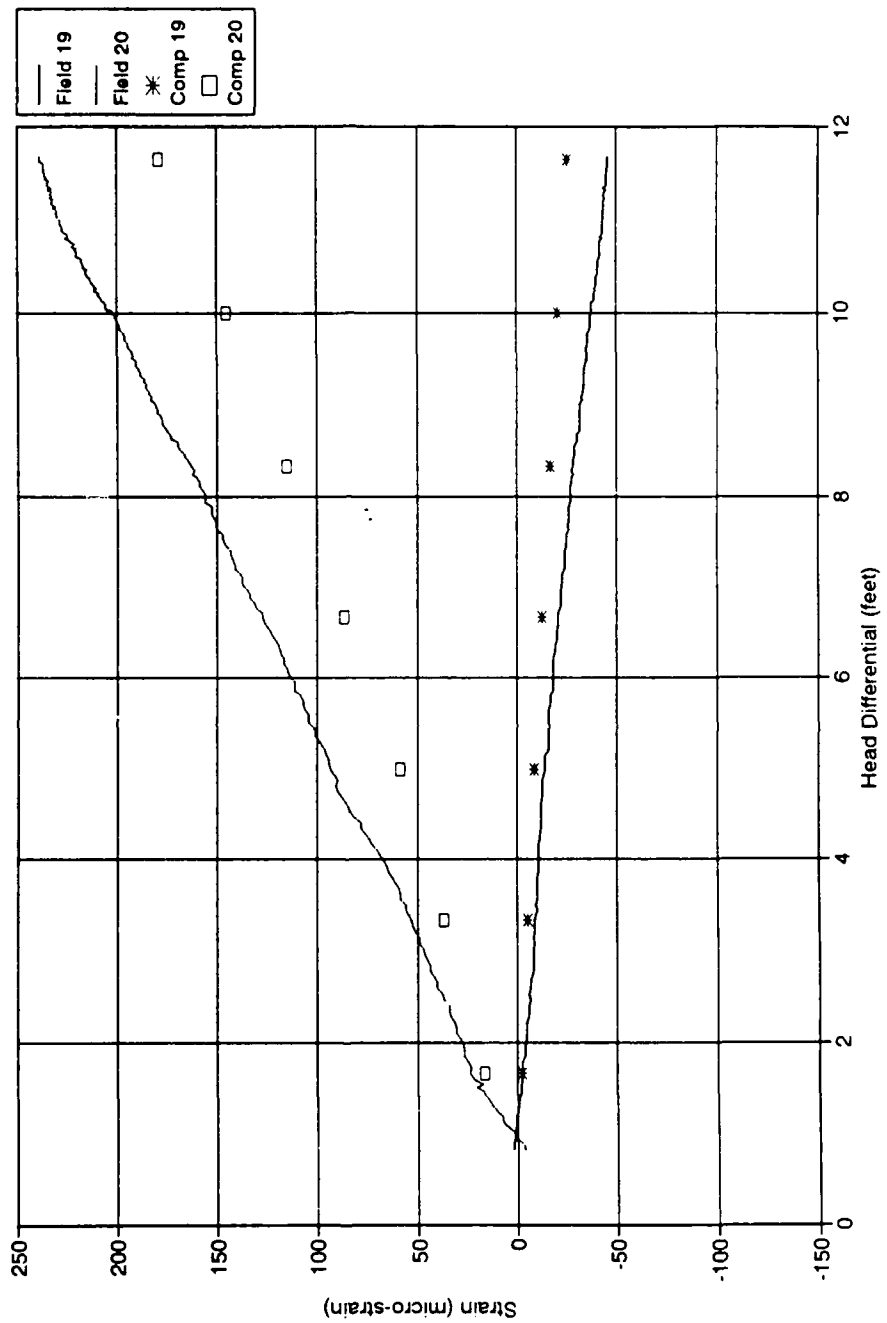
Emsworth: Strain vs. Head Differential  
Channels 15 & 16 - Diagonals in Bay 2



Emsworth: Strain vs. Head Differential  
Channels 17 & 18 - Miter Girder (Top)

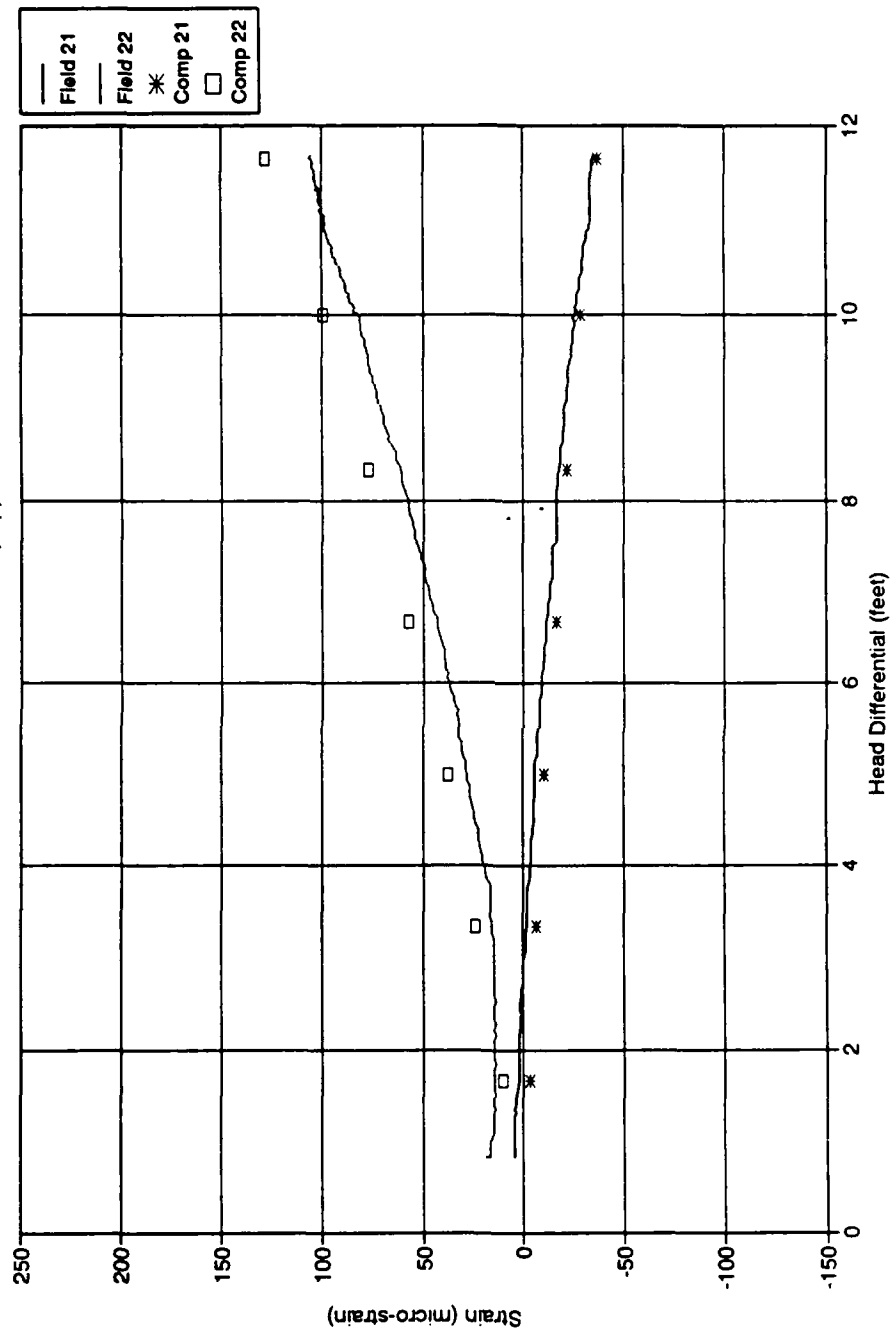


Emsworth: Strain vs. Head Differential  
Channels 19 & 20 - Miter Girder (lower)

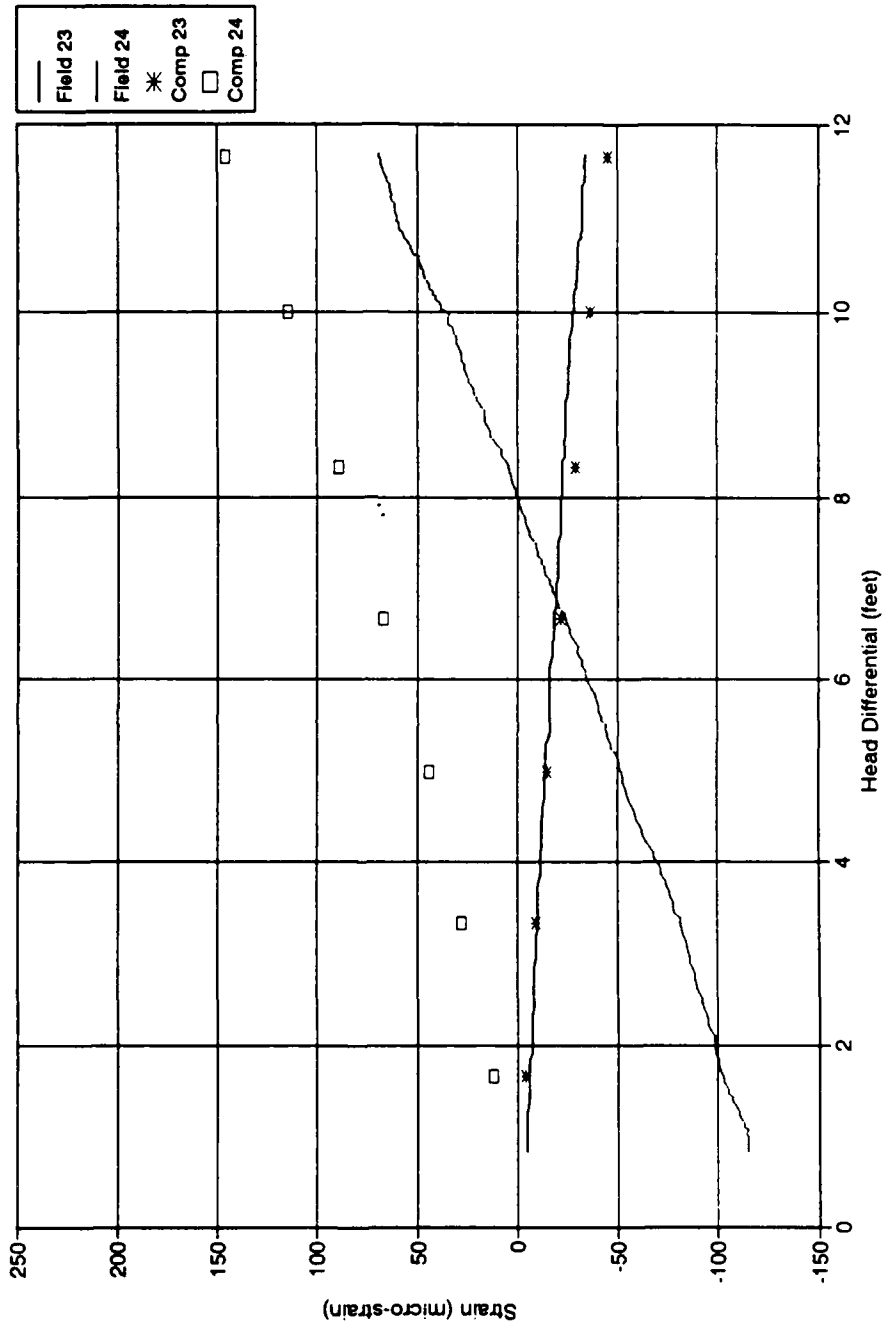




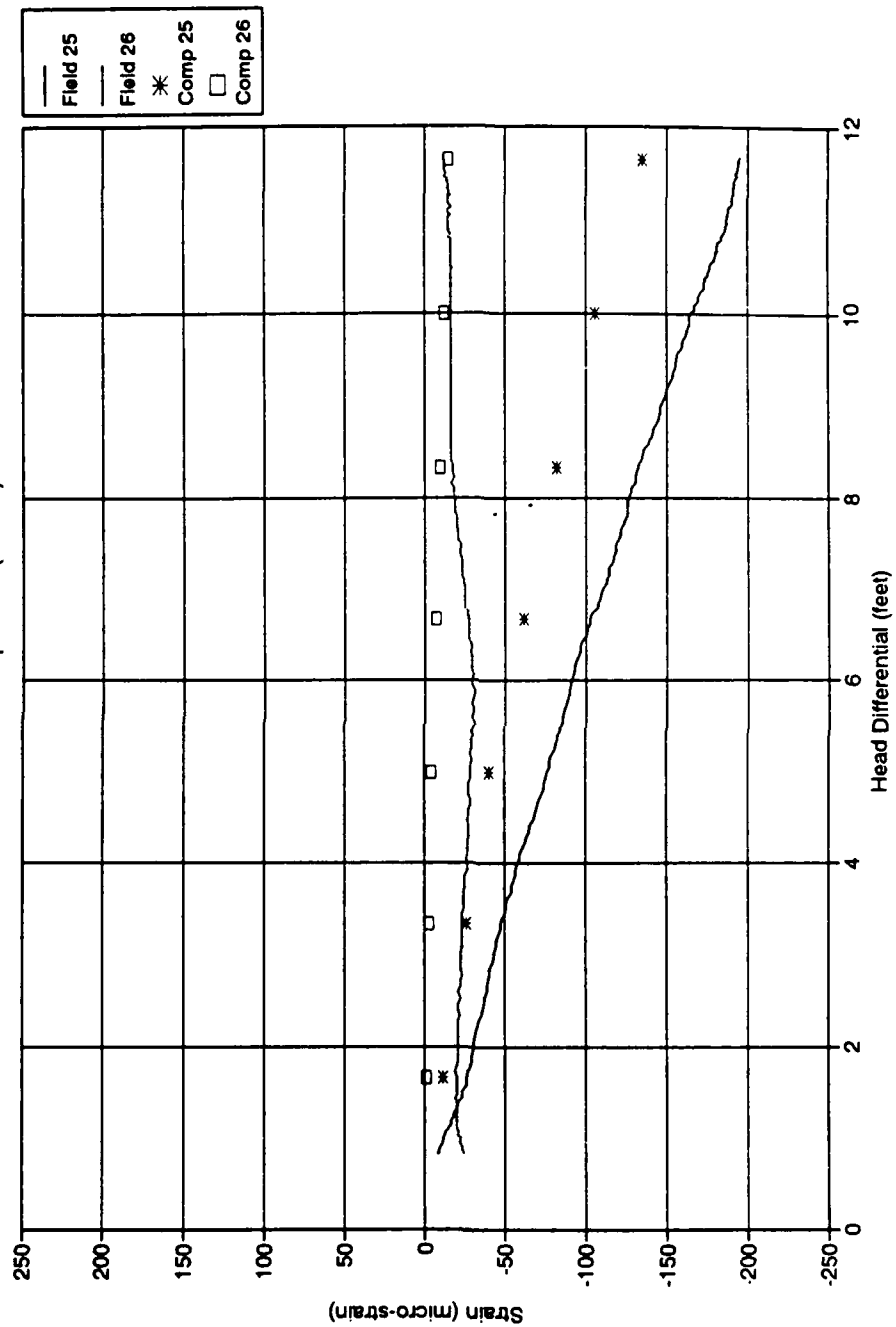
Emsworth: Strain vs. Head Differential  
Channels 21 & 22 - V. Beam 5 (Top)



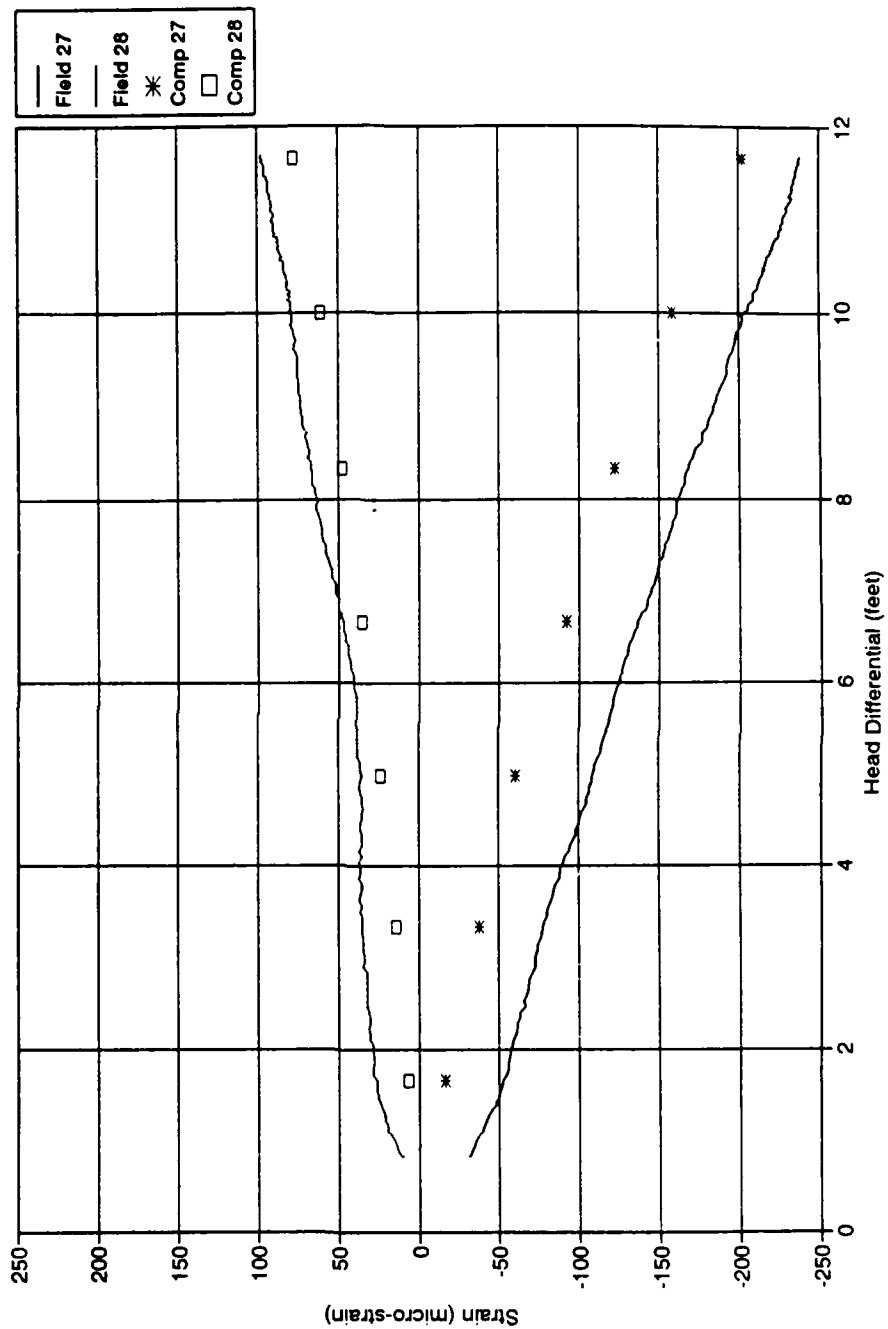
Emsworth: Strain vs. Head Differential  
Channels 23 & 24 - V. Girder (Top)



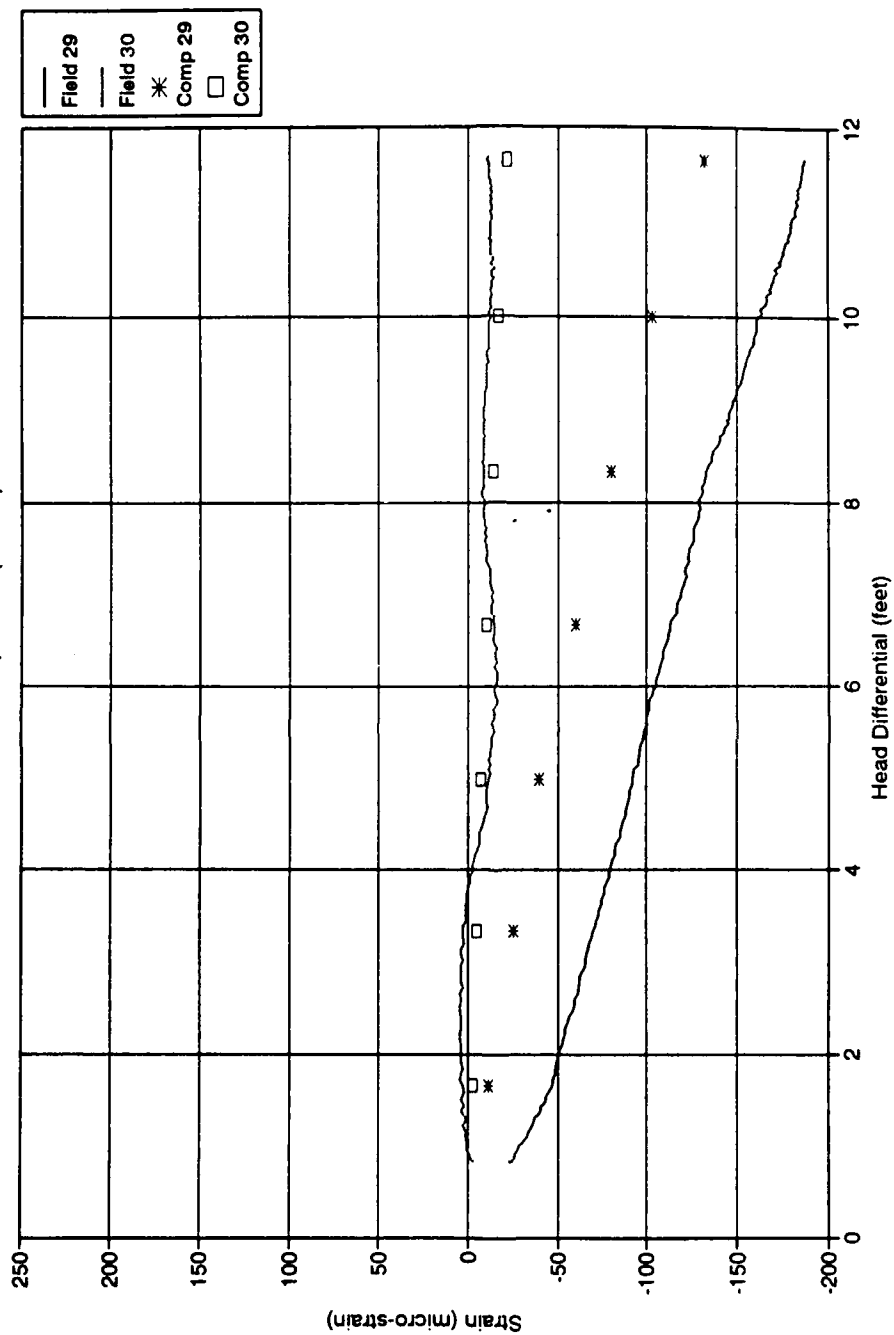
Emsworth: Strain vs. Head Differential  
Channels 25 & 26 - Top Girder (M. End)



Emsworth: Strain vs. Head Differential  
Channels 27 & 28 - Top Girder (Mid)



Emsworth: Strain vs. Head Differential  
Channels 29 & 30 - Top Girder (Q. End)

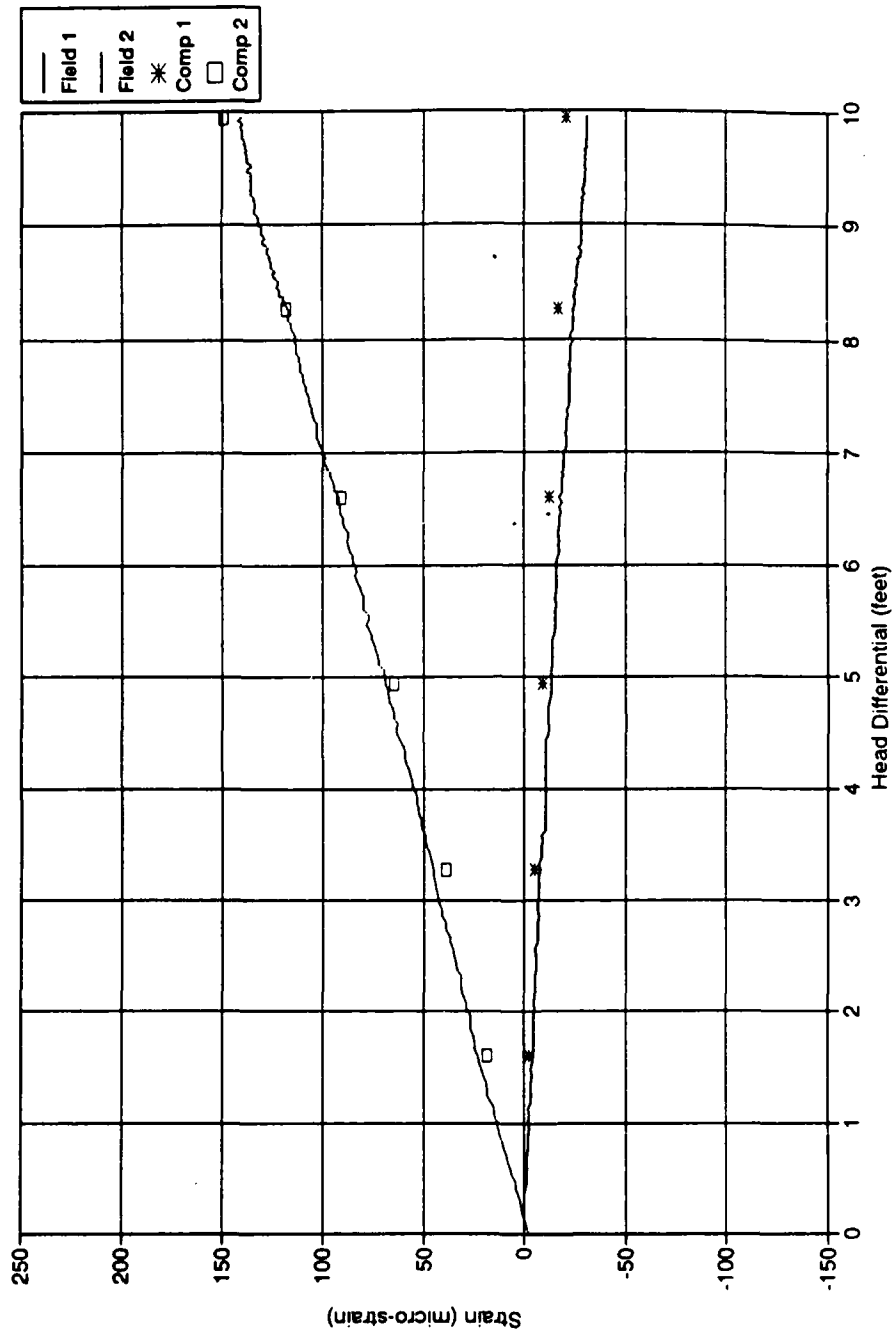


## **Appendix B Strain History Comparisons (Low Pool Raised 20 In.)**

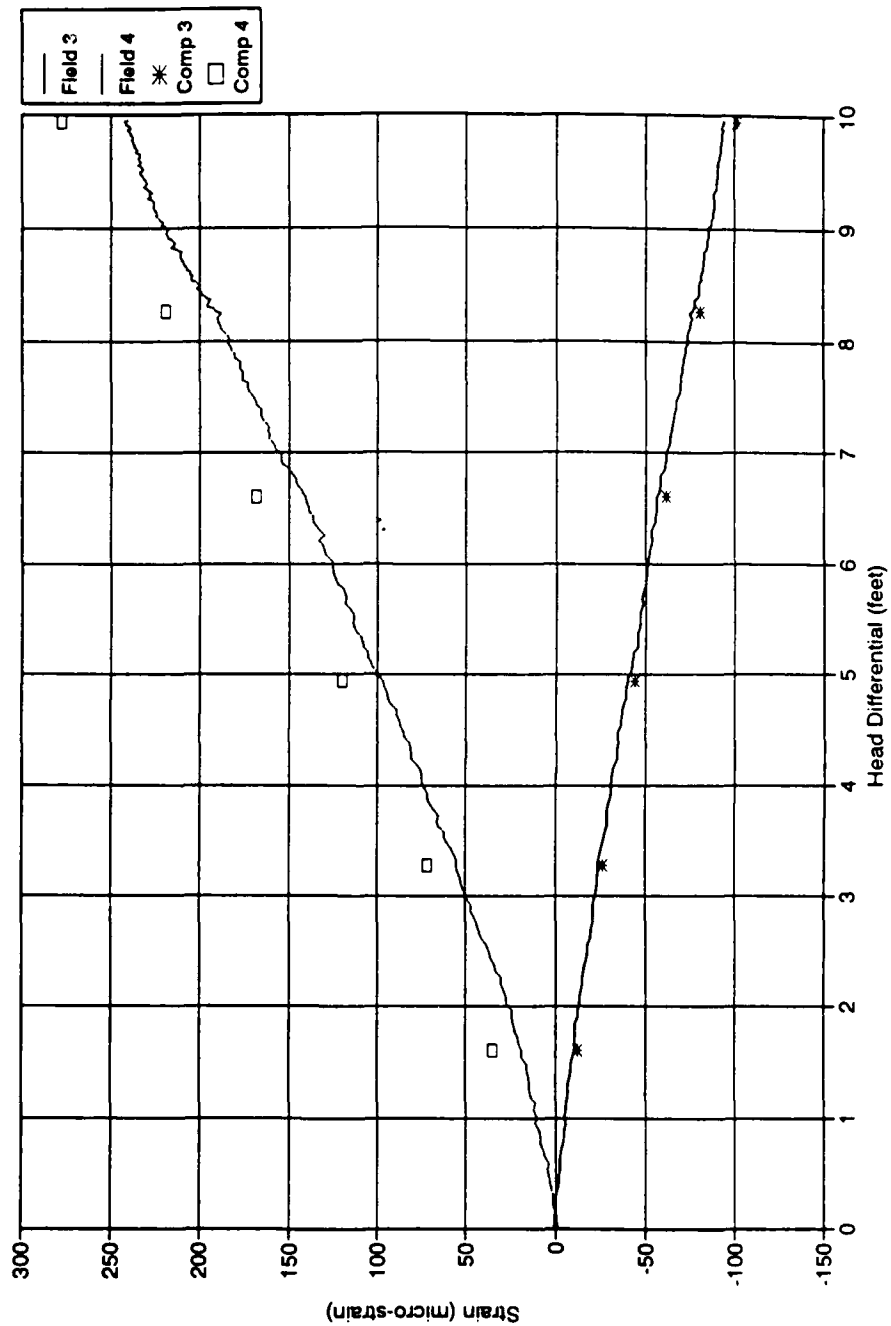
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The following figures contain graphs of strain history as a function of head differential for the analysis results and modified field data. Each figure includes a legend description that identifies the transducer location by data acquisition system channel number. The term Field refers to field data and the term Comp refers to analytical data. It was assumed in the analysis that the lower pool elevation was 20 in. higher than actual. Measured field strains associated with the first 20 in. of head differential are eliminated from the data file. Strain readings corresponding to 20 in. of head differential are subtracted from the remaining data to simulate the effect of a raised lower pool level.

Emsworth: Strain vs. Head Differential  
Channels 1 & 2 - Quoin Girder

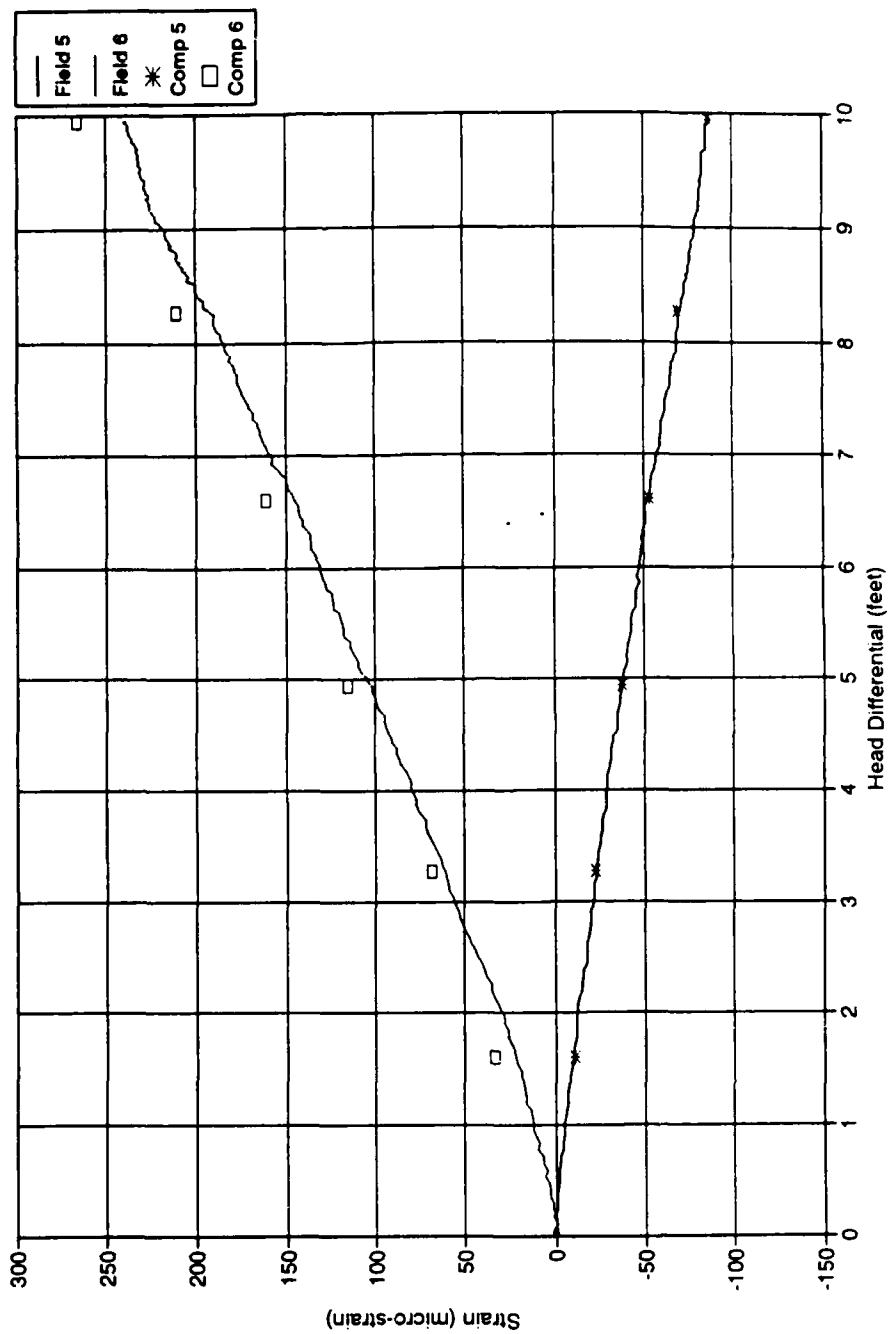


Emsworth: Strain vs. Head Differential  
Channels 3 & 4 - V. Beam 3

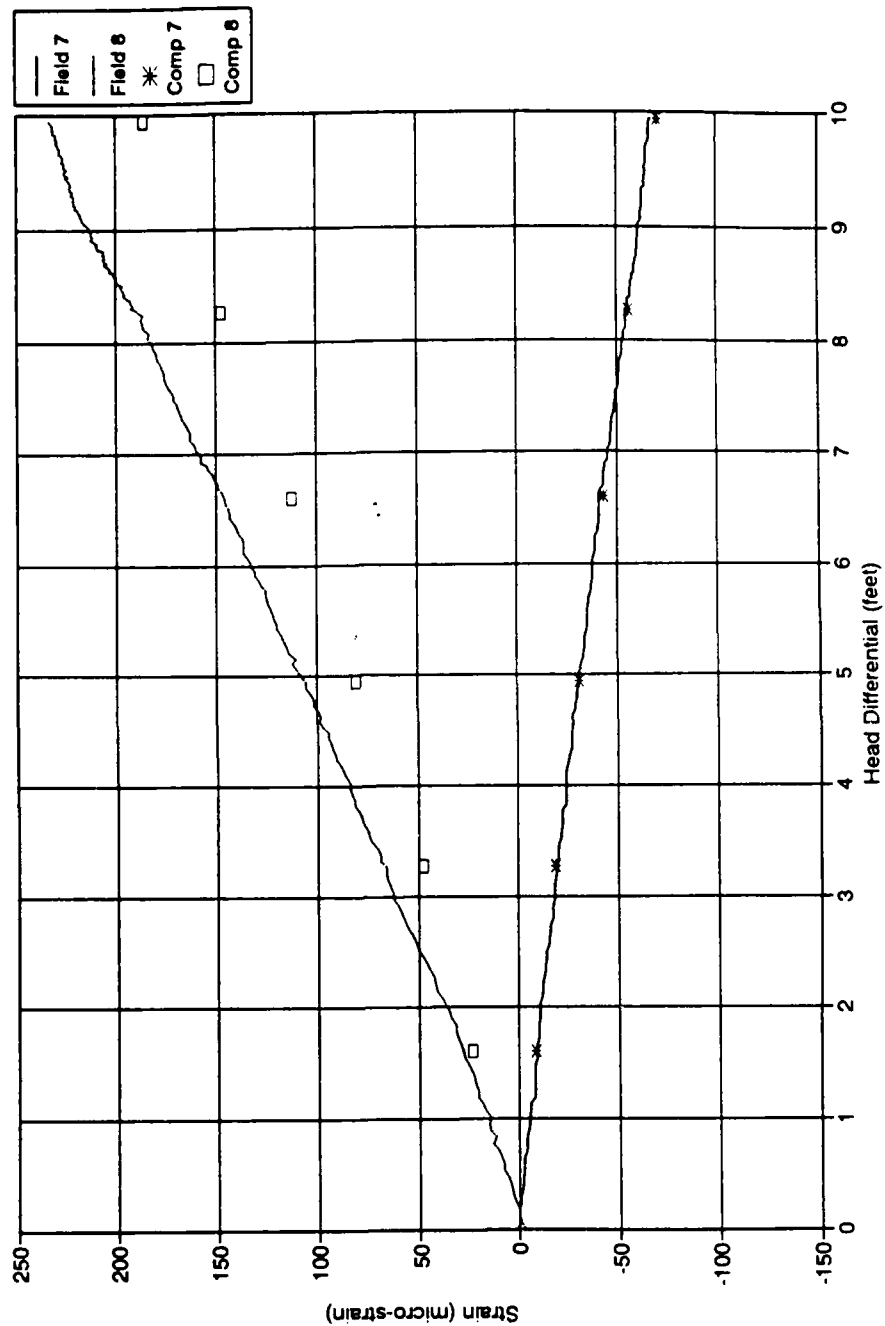




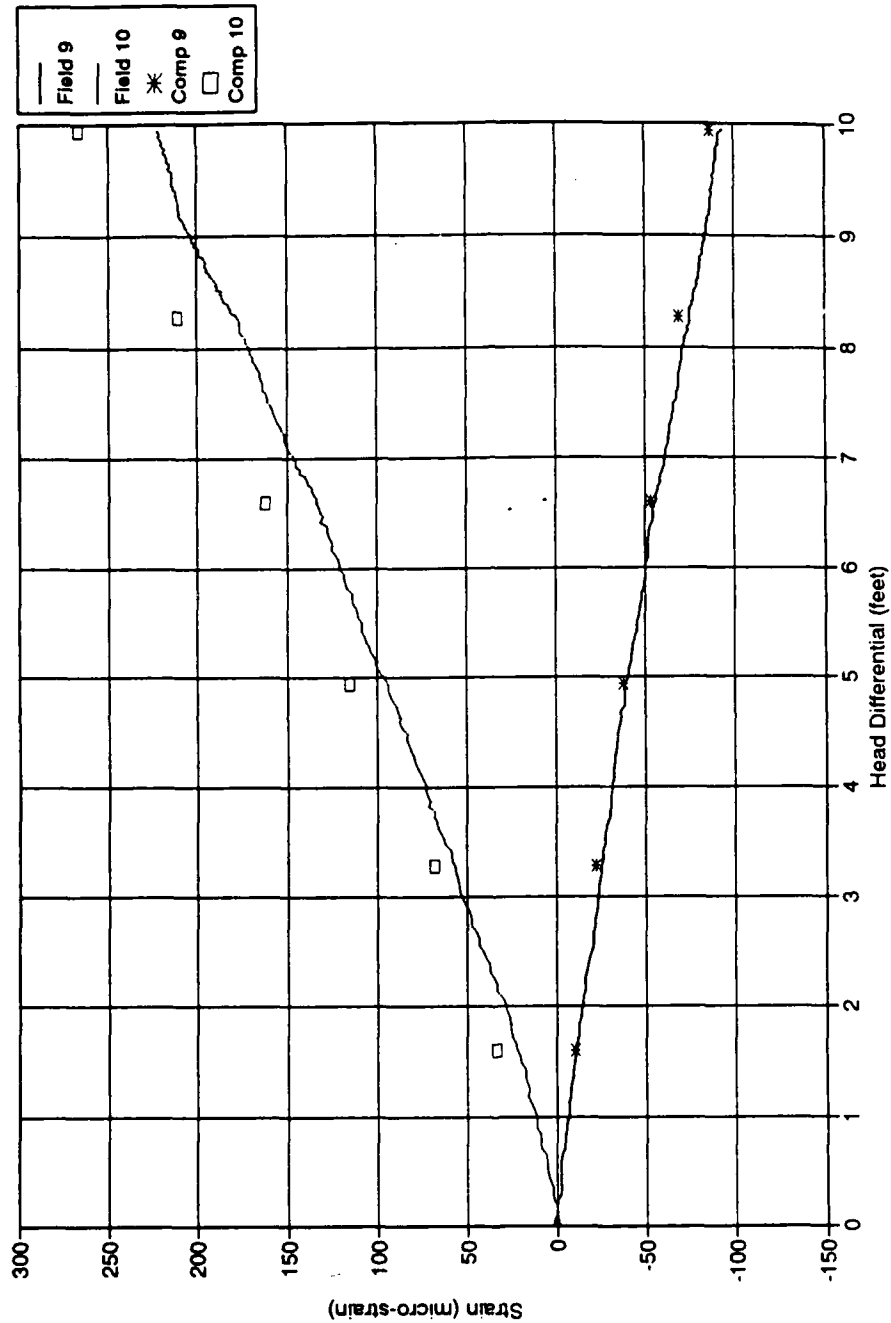
Emsworth: Strain vs. Head Differential  
Channels 5 & 6 - V. Beam 5



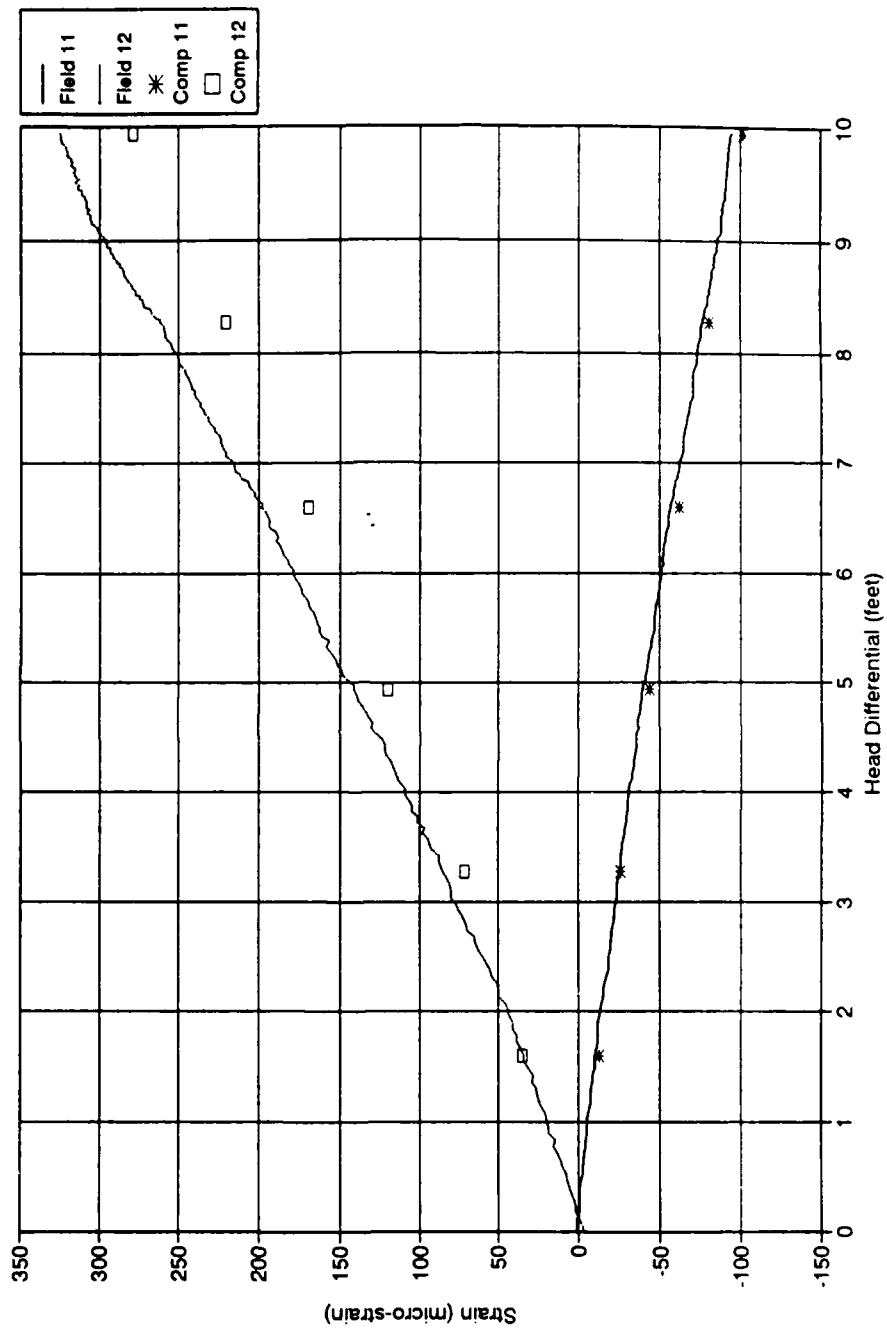
Emsworth: Strain vs. Head Differential  
Channels 7 & 8 - V. Girder (lower)



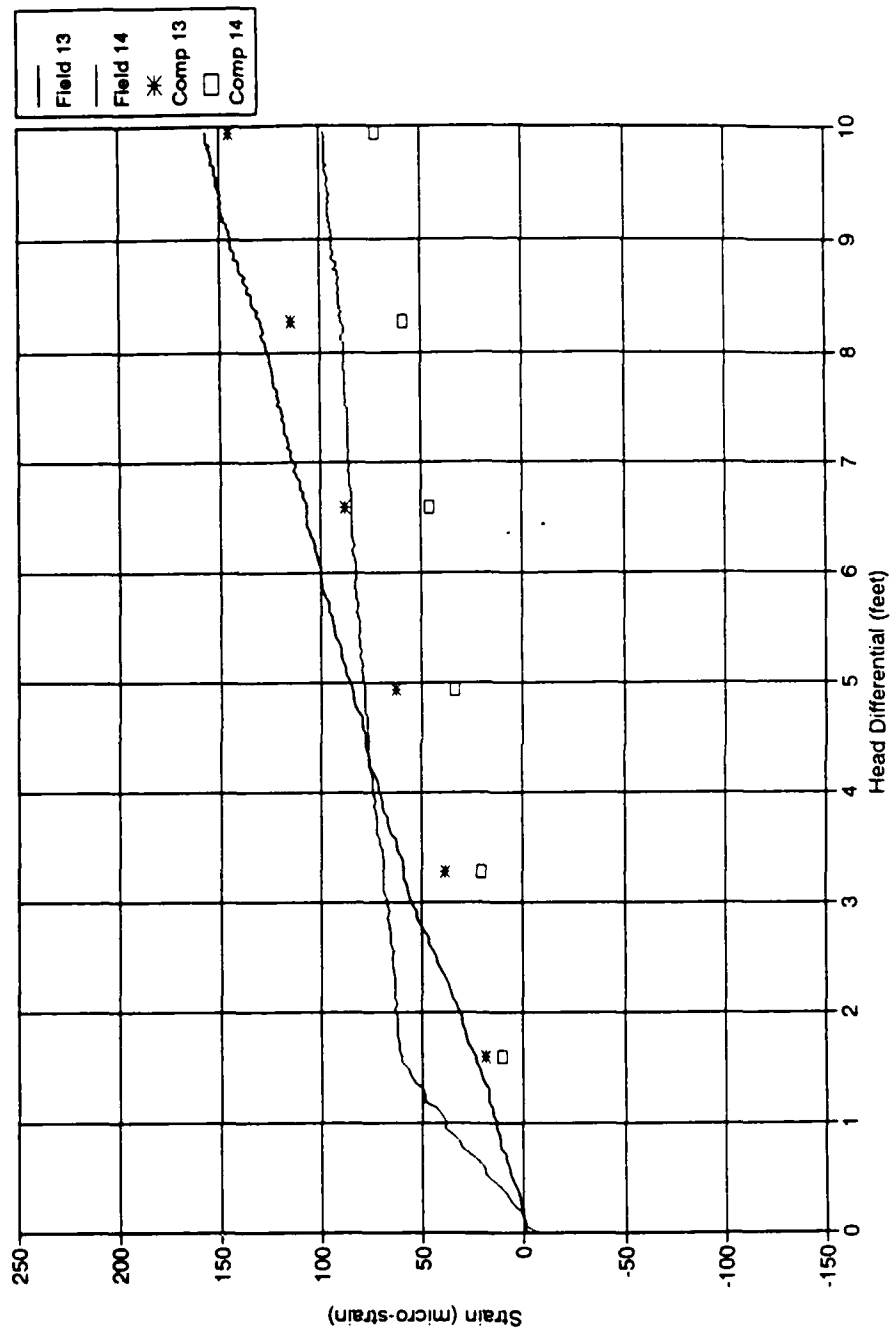
Emsworth: Strain vs. Head Differential  
Channels 9 & 10 - V. Beam 6



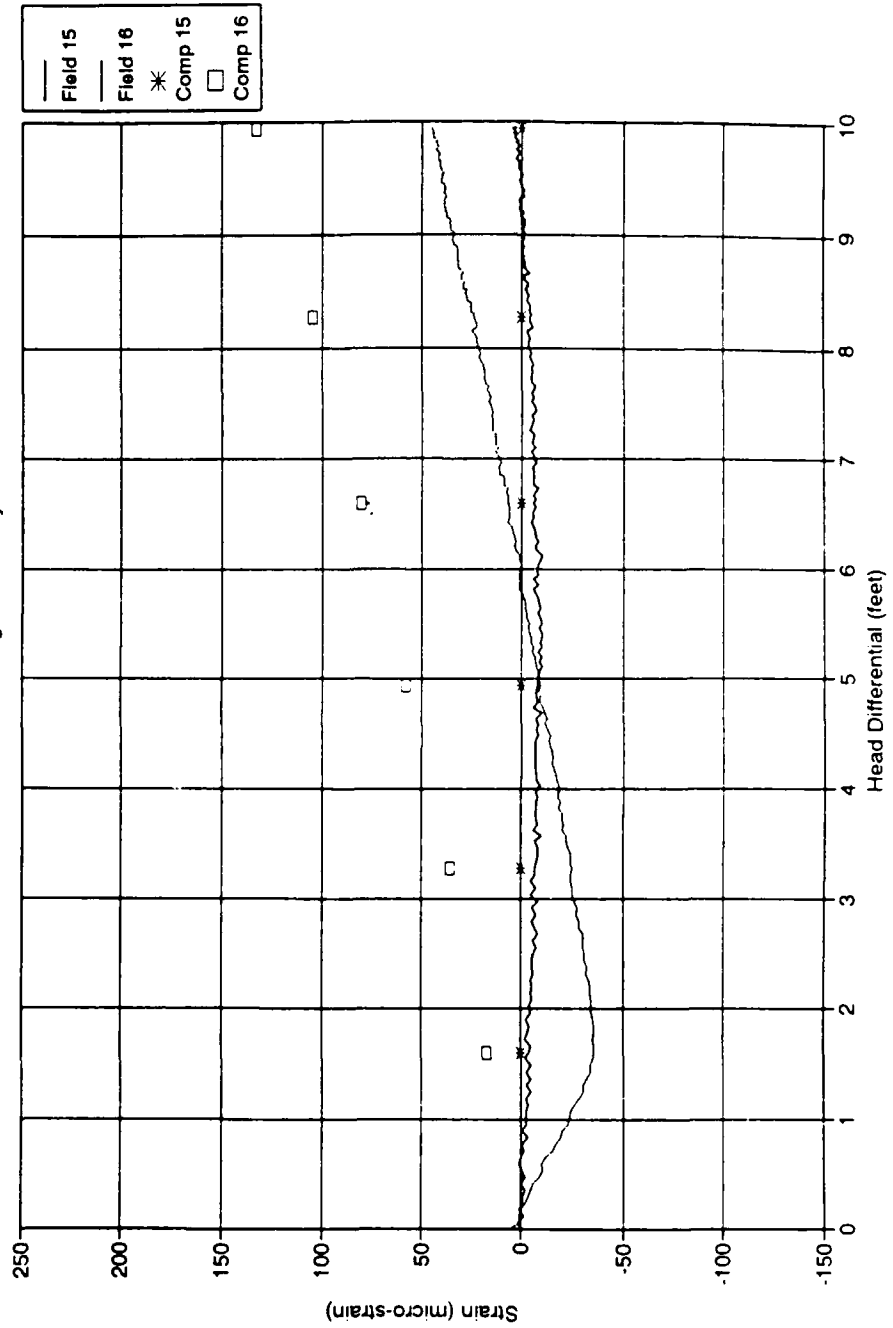
Emsworth: Strain vs. Head Differential  
Channels 11 & 12 - V. Beam 8



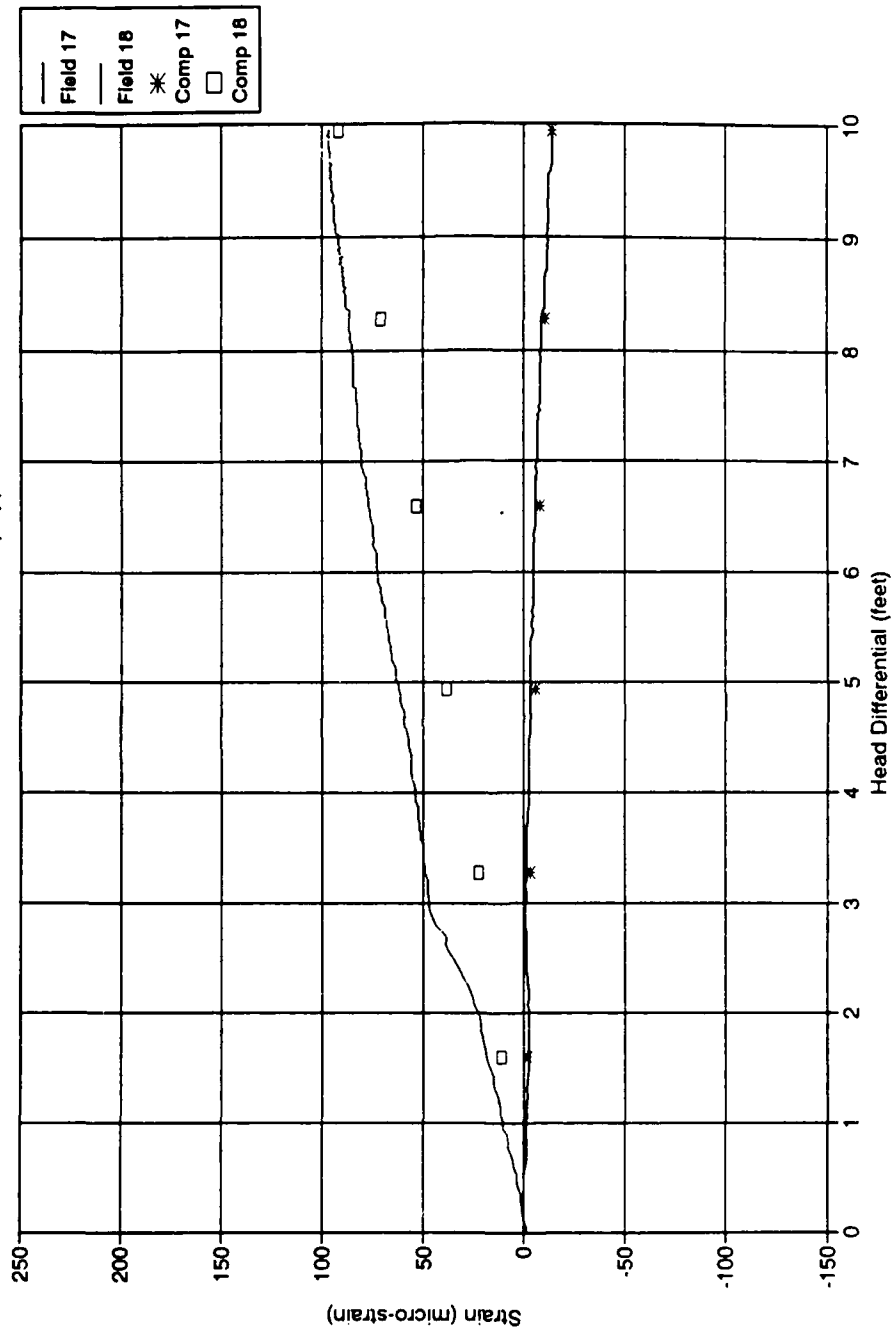
Emsworth: Strain vs. Head Differential  
Channels 13 & 14 - Diagonals in Bay 1



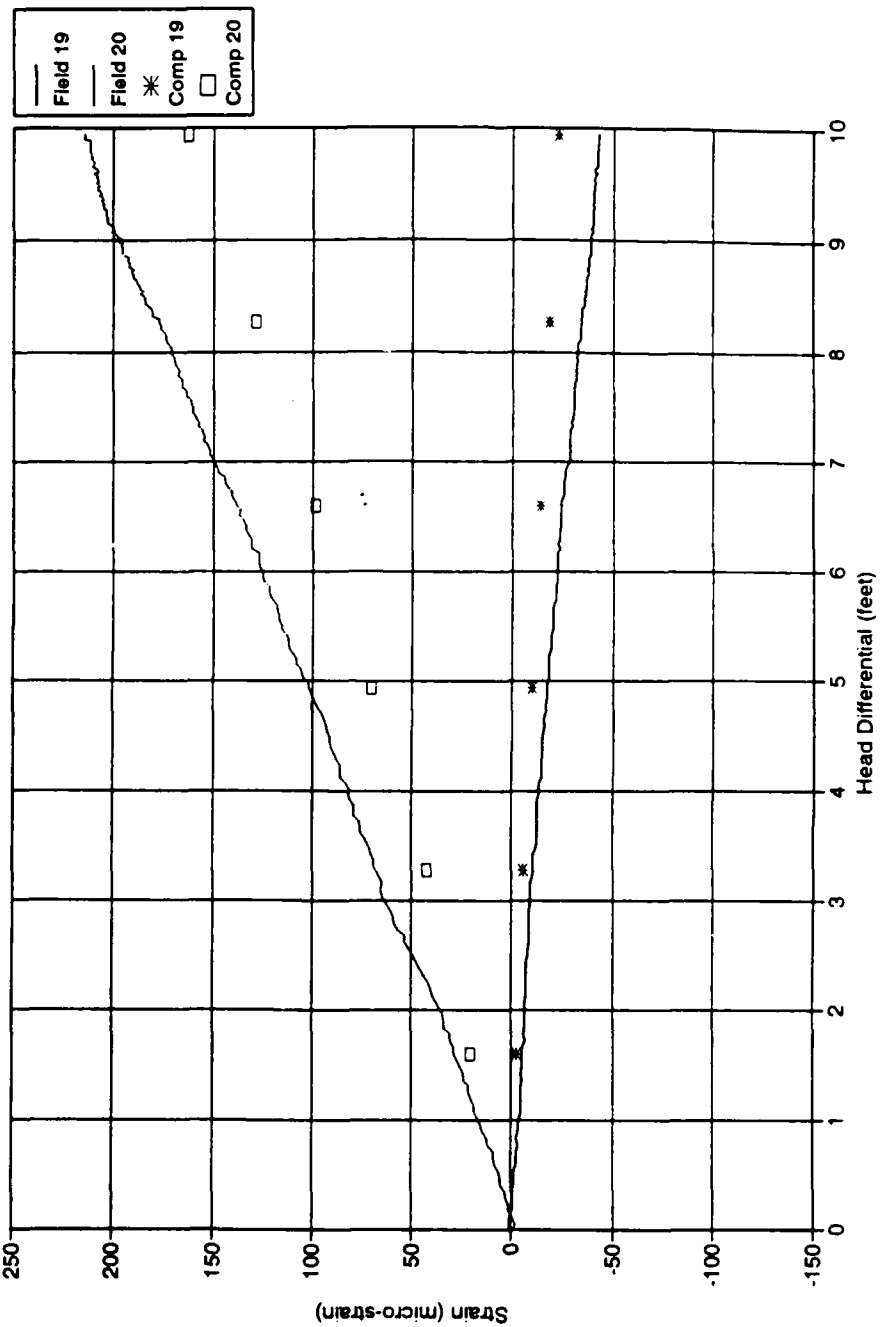
Emsworth: Strain vs. Head Differential  
Channels 15 & 16 - Diagonals in Bay 2



Emsworth: Strain vs. Head Differential  
Channels 17 & 18 - Miter Girder (Top)

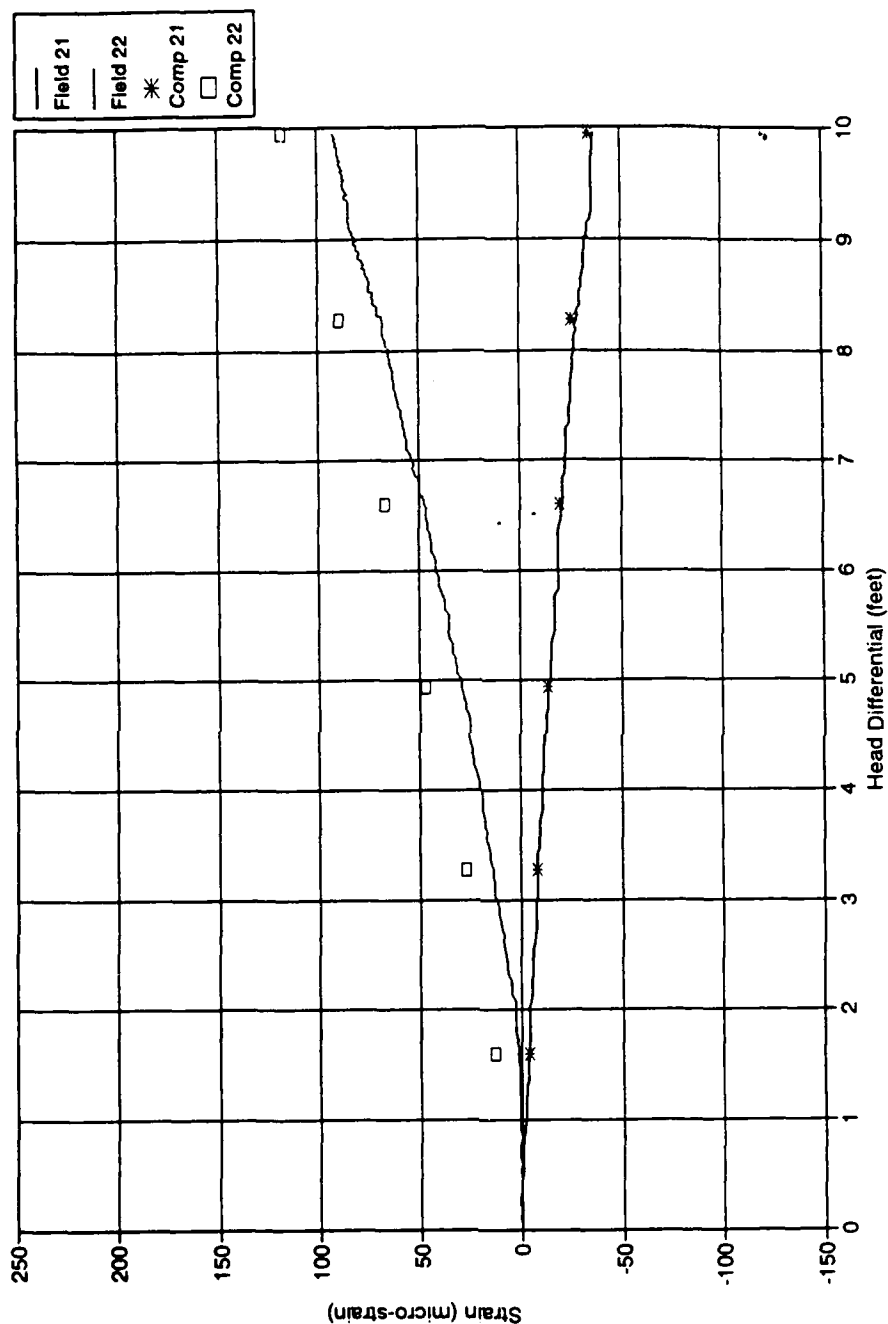


Emsworth: Strain vs. Head Differential  
Channels 19 & 20 - Miter Girders (lower)

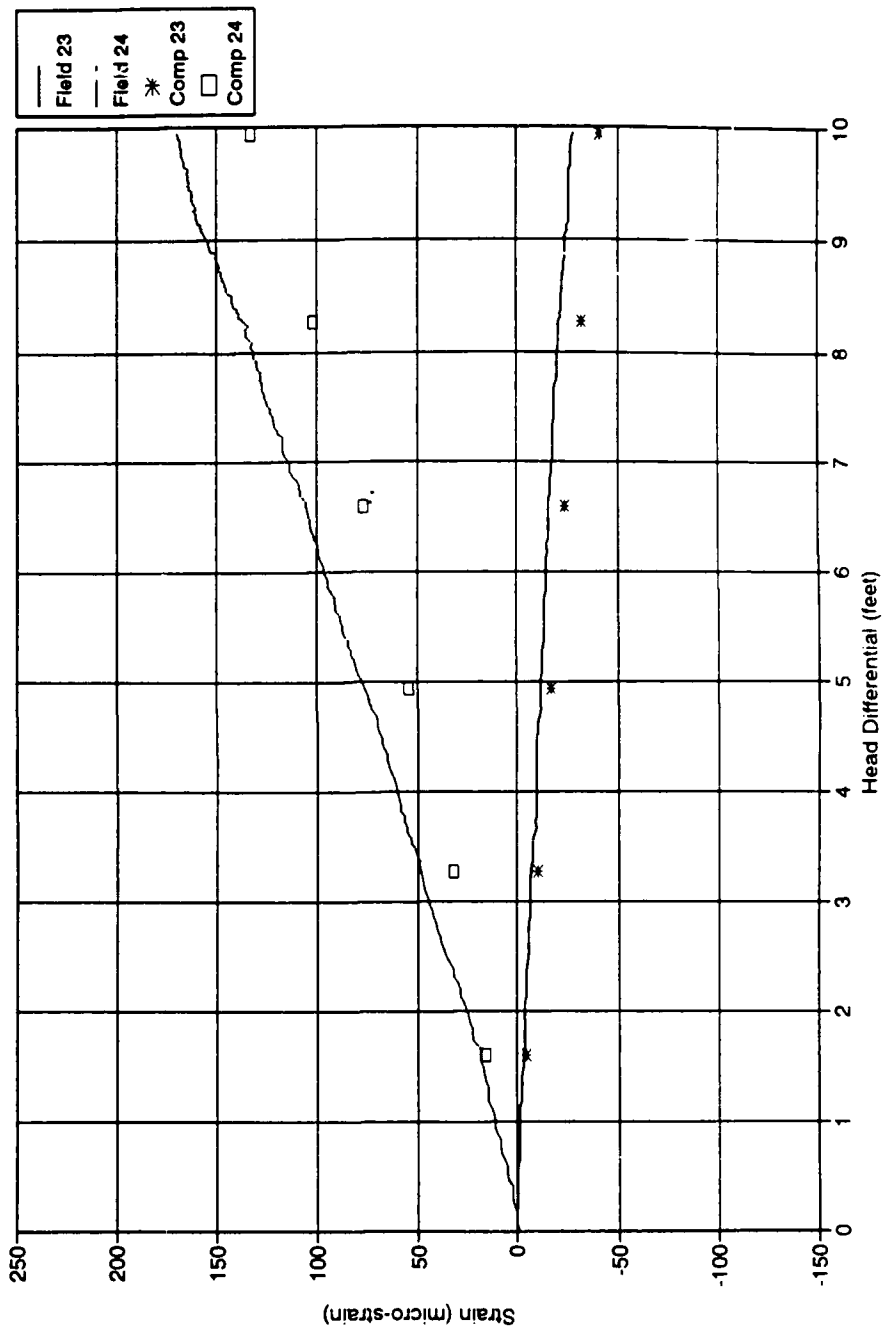




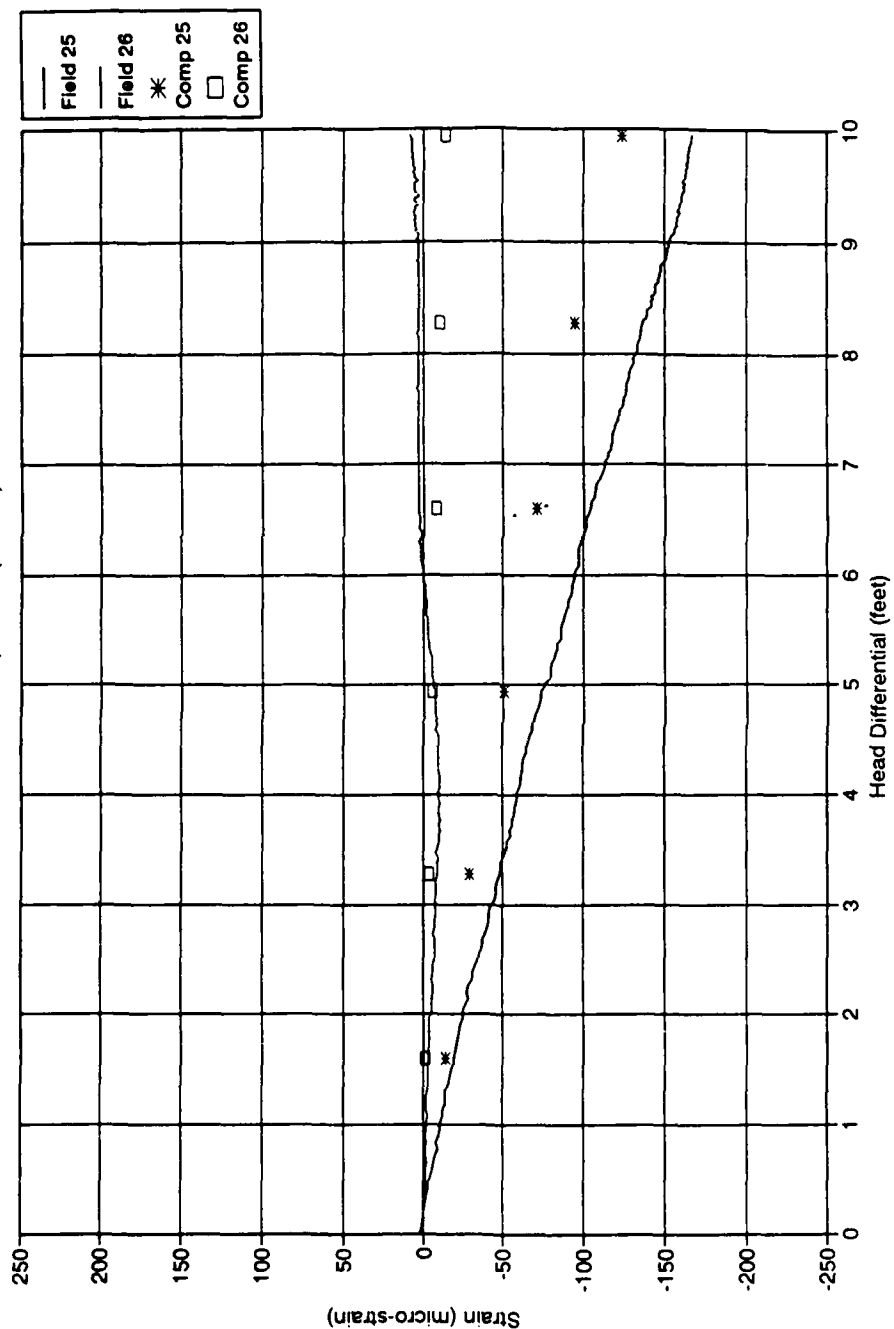
Emsworth: Strain vs. Head Differential  
Channels 21 & 22 - V. Beam 5 (Top)



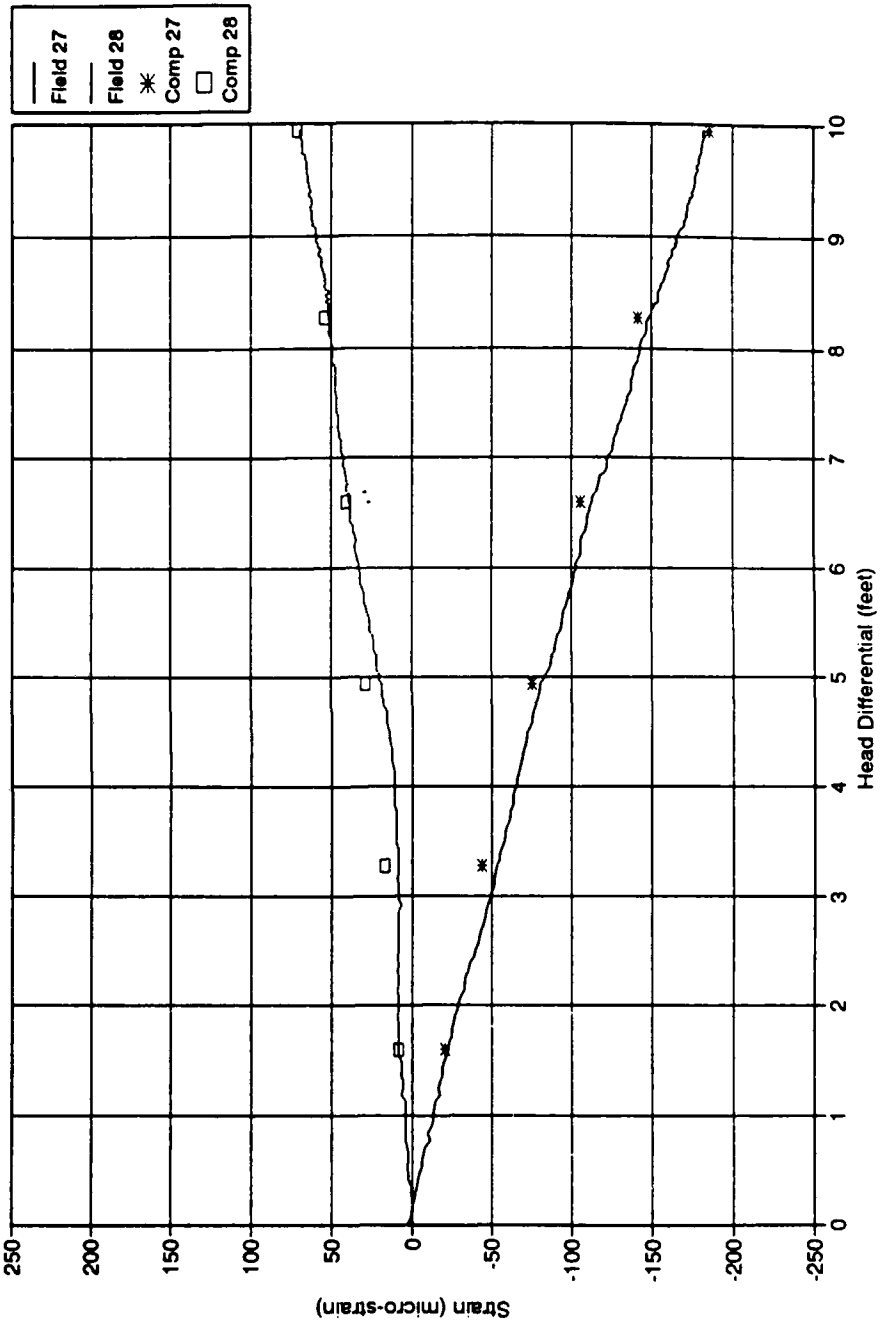
Emsworth: Strain vs. Head Differential  
Channels 23 & 24 - V. Girder (Top)



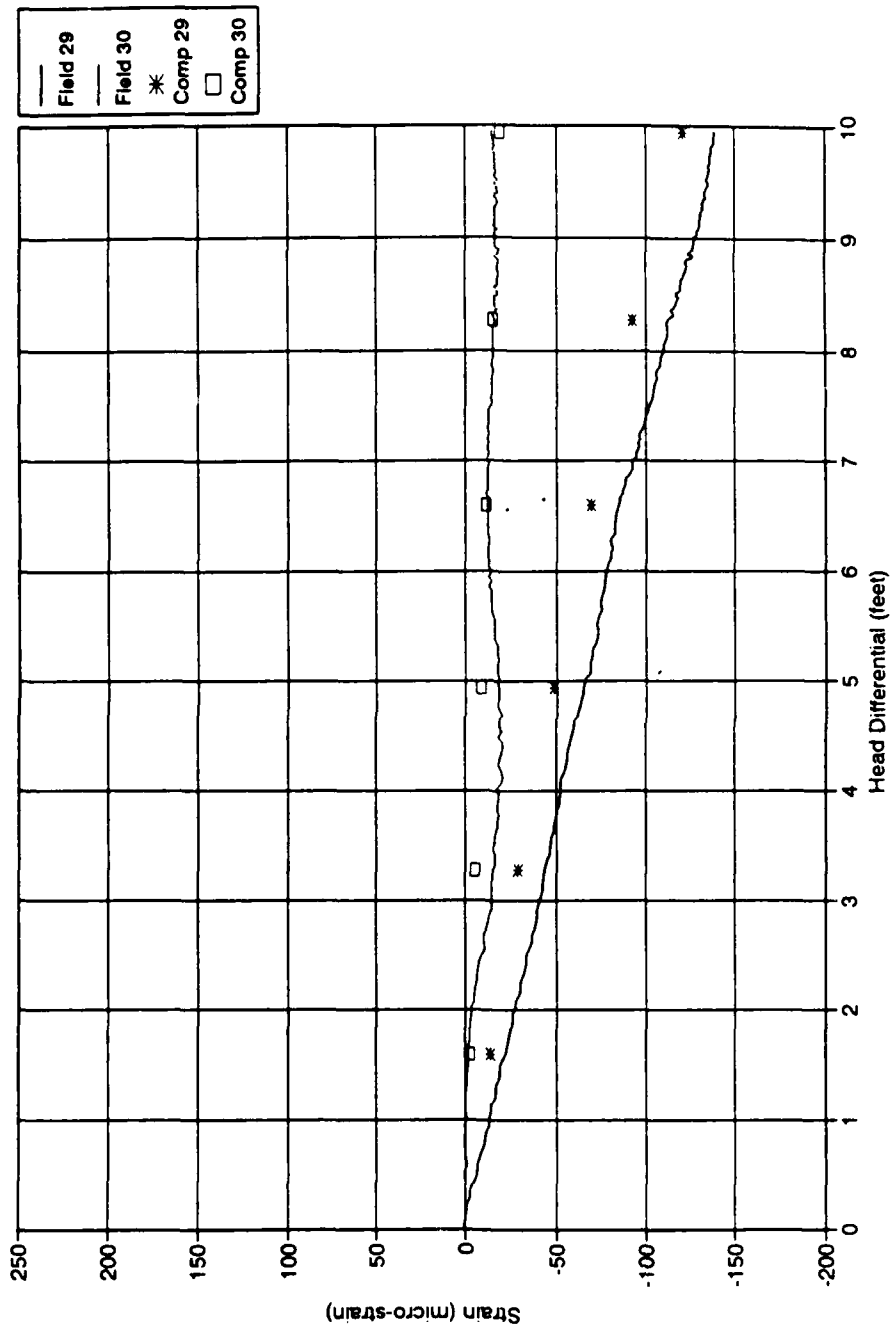
Emsworth: Strain vs. Head Differential  
Channels 25 & 26 - Top Girder (M. End)



Emsworth: Strain vs. Head Differential  
Channels 27 & 28 - Top Girder (Mid)



Emsworth: Strain vs. Head Differential  
Channels 29 & 30 - Top Girder (Q. End)



# **Appendix C**

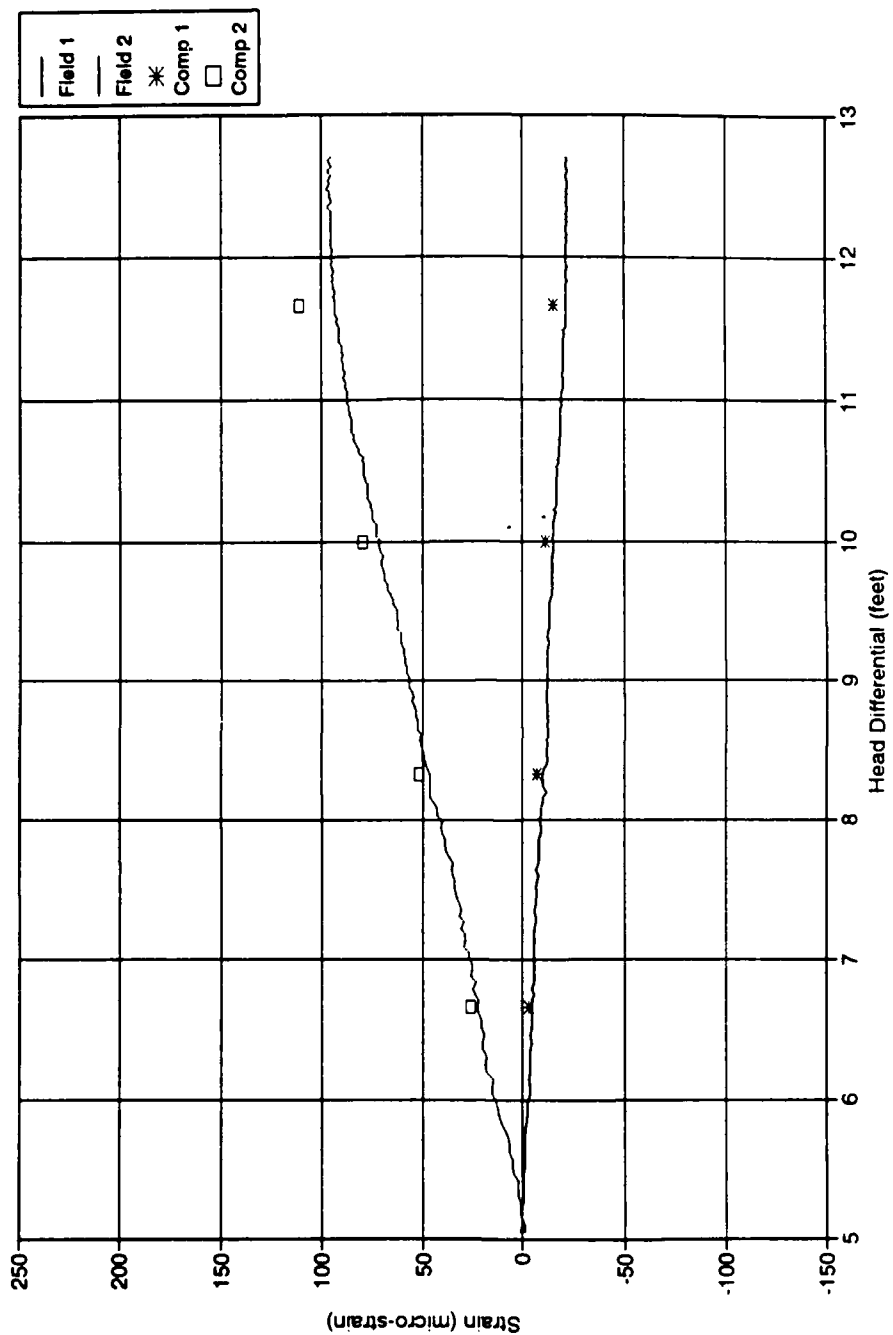
## **Strain History Comparisons**

### **(Low Pool Raised 60 In.)**

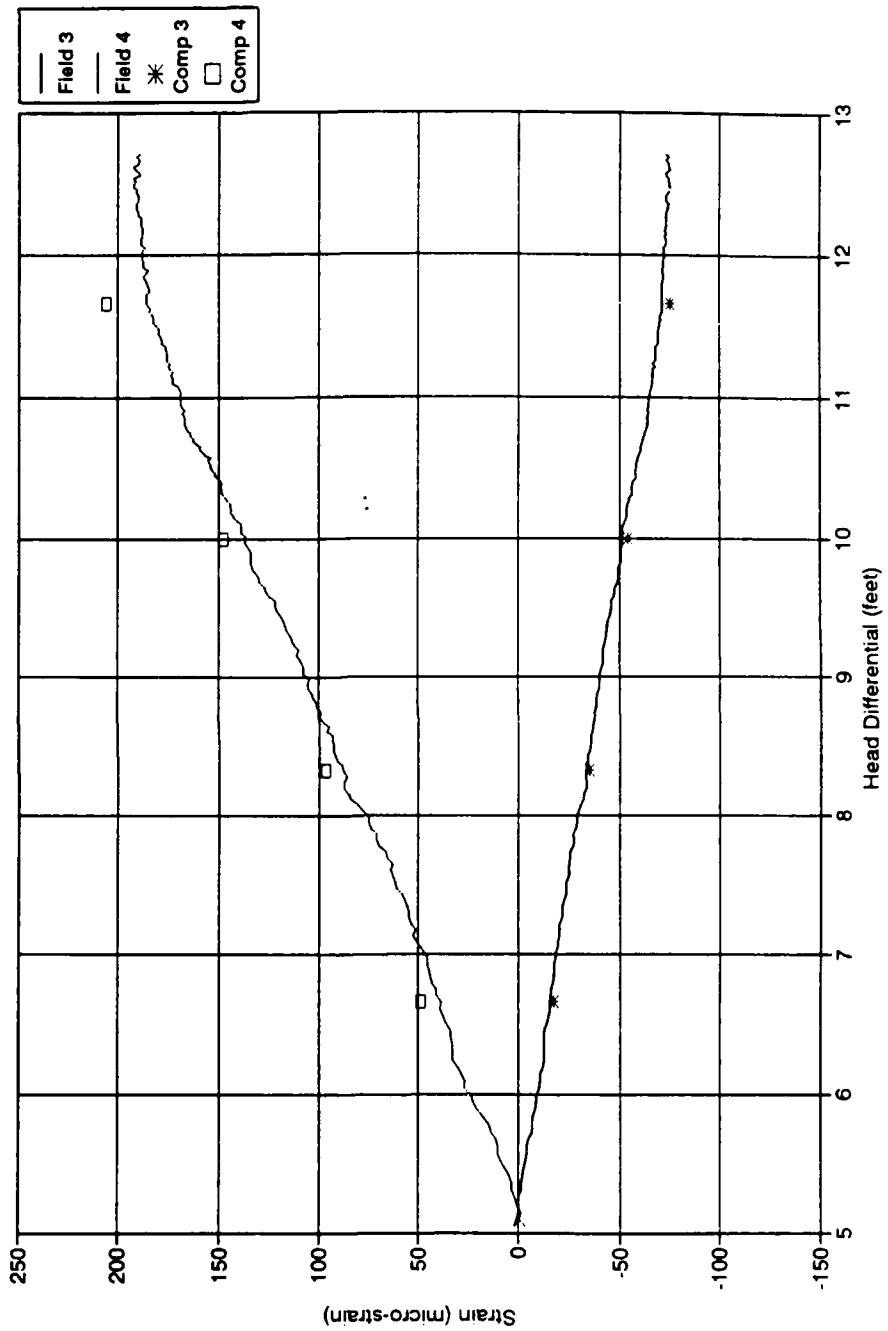
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The following figures contain graphs of strain history as a function of head differential for the analysis results and modified field data. Each figure includes a legend description that identifies the transducer location by data acquisition system channel number. The term Field refers to field data and the term Comp refers to analytical data. It was assumed in the analysis that the lower pool elevation was 60 in. higher than actual. Measured field strains associated with the first 60 in. of head differential are eliminated from the data file. Strain readings corresponding to 60 in. of head differential are subtracted from the remaining data to simulate the effect of a raised lower pool level.

Emsworth: Strain vs. Head Differential  
Channels 1 & 2 - Quoin Girder

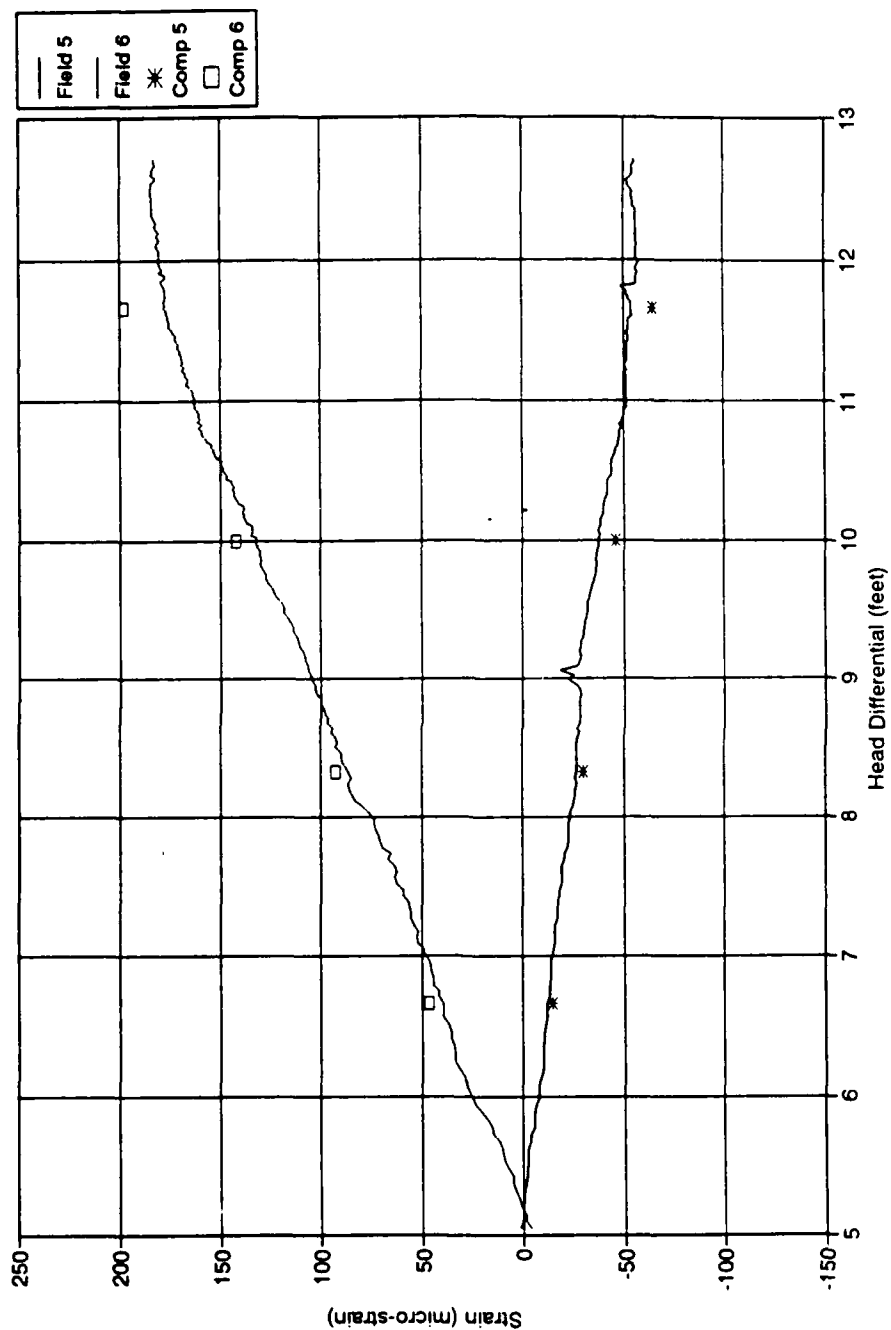


Emsworth: Strain vs. Head Differential  
Channels 3 & 4 - V. Beam 3

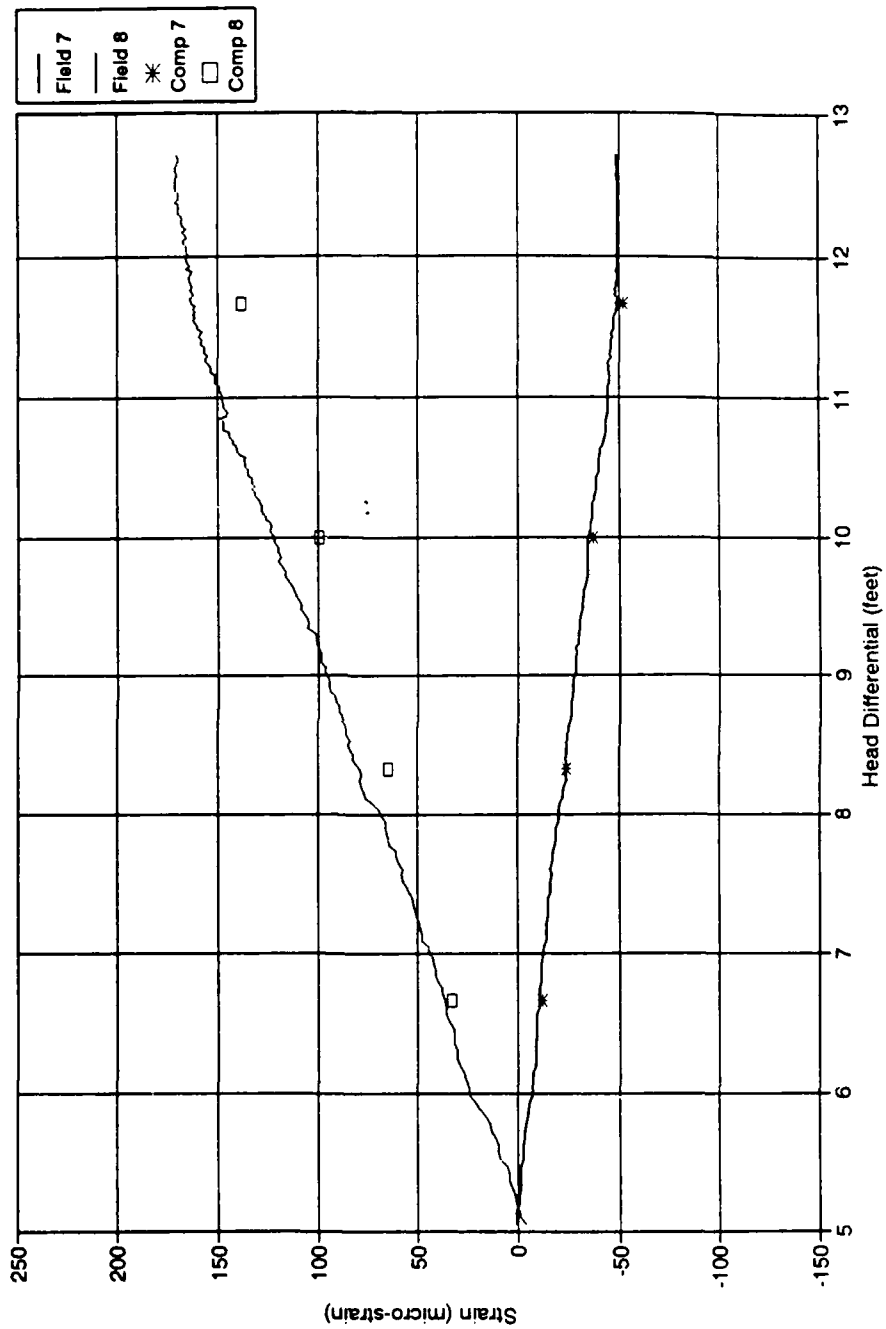




Emsworth: Strain vs. Head Differential  
Channels 5 & 6 - V. Beam 5



Emsworth: Strain vs. Head Differential  
Channels 7 & 8 - V. Girder (lower)



# Biological inventories in Hawaii help Army protect flora & fauna

Kristine Bacharach

25th Infantry Division Public Affairs Office

the location and status of resources, assessing management issues, and implementing key management actions.

SCHOFIELD BARRACKS, Hawaii—The Department of Defense manages more than 24 million acres of land in the United States, and in Hawaii alone, the Army is steward for more than 165,000 acres. These lands possess an irreplaceable collection of natural and cultural resources.

The Legacy Resource Management Program was established by the Defense Department in 1991 to identify, protect, and provide guidance for the management of significant biological, geophysical, cultural, and historical resources on or involving defense lands. Under the Legacy program, which has grown from \$10 million in funding in 1991 to about \$50 million in 1993, military installations and zoologists to help complete the enormous task throughout the United States are taking part in demonstration projects to protect the nation's natural and cultural resources.

An inventory of biological resources at Schofield Barracks in cooperation with the Nature Conservancy is one such demonstration project. The goal of the project is to enhance protection of threatened and endangered and rare ecosystems.

The protection will come from identifying

management issues, and implementing key management actions.

According to Patrick Ching, agronomist and land manager, a three-part effort will help conserve natural resources in Hawaii.

First, inventories are completed. Following this action, threats to natural resources are evaluated, and then a management plan is developed. Schofield Barracks is currently at this stage. Among the agencies that assisted with the inventory was Colorado State University. The school's botanists, biologists, and zoologists to help complete the enormous task.

The plan will permit a course to protect the species of plants and animals. Ching said. With the "biodiversity" of plant life in Hawaii, containing more endangered species than at any Army installation, it is a high priority. The project will have participants in the Legacy program will have their hands full.

"We are trying to find the best ways to protect the plants and animals," Salley said.

Archaeologists find 200-year-old artifacts at Presidio of S.F.

PRESIDIO OF SAN FRANCISCO, Calif.—U.S. Army Corps of Engineers archaeological consultants have made a major discovery on the Presidio of San Francisco. The remains of a Spanish military building, discovered during an underground-storage-tank removal could mark the very beginning of Spanish presence in the San Francisco Bay area.

Archaeologist Vance Beale, of Woodward-Clyde Consultants, said the stone wall appears to be from the era of the founding of Presidio in the late 1700s. Artifacts, including part of the rock foundations of the building, adobe bricks, dishes, and tools used by Spanish troops, are at least 200 years old.

The original Presidio was thought to be situated approximately 100 yards square. This find is just outside the area where the original Presidio was built. Beale thinks the building might have been a case-

ment, or building used to store gunpowder and munitions.

More extensive study will be required to determine the extent of the wall. Once this is done, it may be possible to define even better how the original Presidio looked.

The discovery was made in the back yard of a set of family housing quarters on Funston Avenue inside the Presidio. The Funston Avenue family housing buildings are historic as well, having been constructed during the 1860s and 1870s.

A 1994 excavation that led to the wall's discovery is part of ongoing environmental projects conducted by the Army Golden Gate National Recreation Area.

The work also includes extensive repairs to the Presidio's infrastructure, including repair and replacement of sewer lines. During some of these excavations, pieces of broken dishes from various periods in the Presidio's history have been discovered.

Each of these discoveries is being documented, catalogued, and preserved as part of a significant period in California and American history.

## Fort Belvoir commander signs plan to manage wildlife 'corridor'

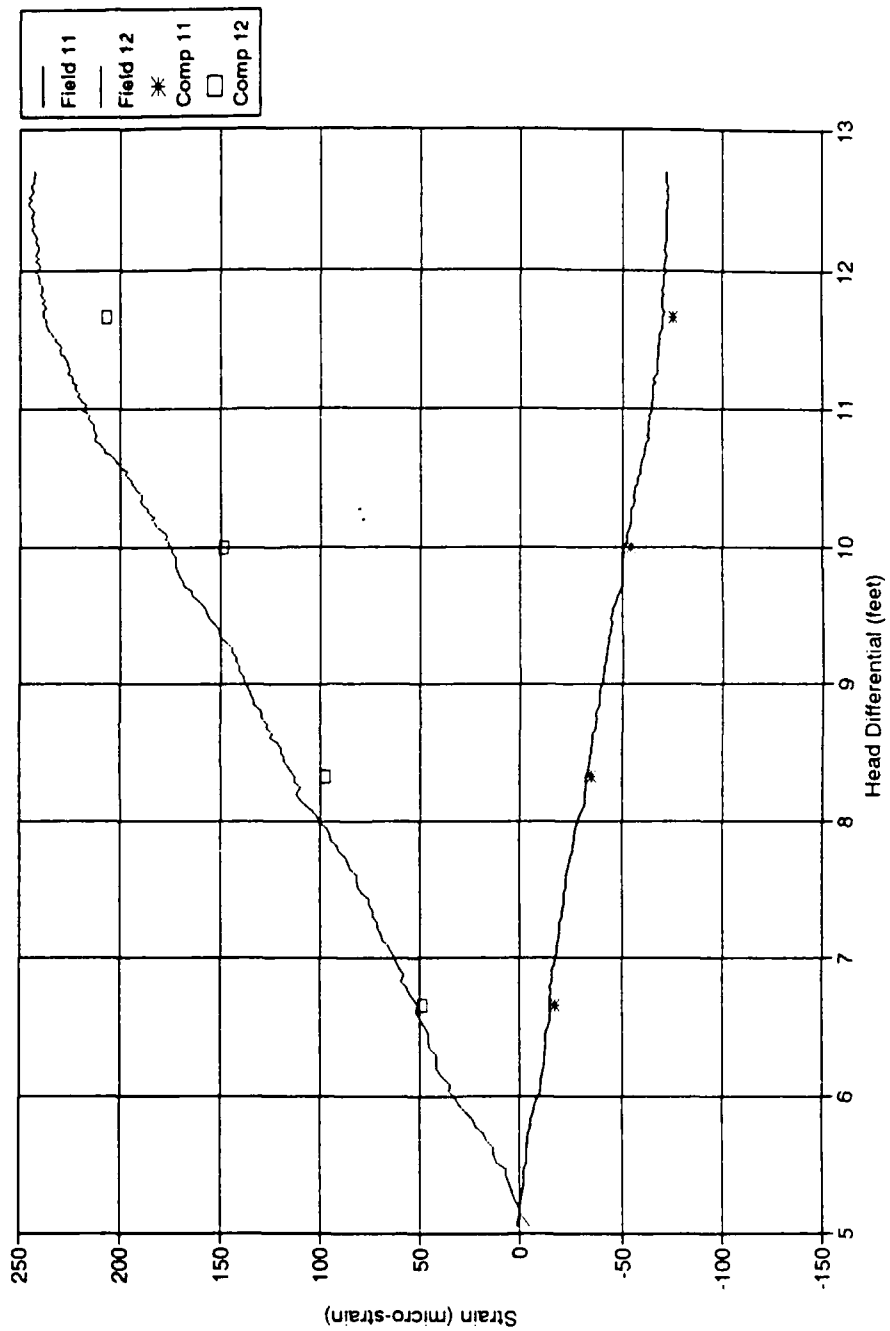
Rebecca Wriggle

naturally existing regional wildlife corri-

"The refuges and connecting corridor explaining how Fort Belvoir, as an open

door that extends roughly from Fairfax taken together total approximately 2,100 most allows outside visitors such as the

Emsworth: Strain vs. Head Differential  
Channels 11 & 12 - V. Beam 8



# Biological inventories in Hawaii help Army protect flora & fauna

Kristine Bacharach

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the location and status of resources, assessing management issues, and implementing key management actions.

SCOTTFIELD BARRACKS, Hawaii—The Department of Defense manages more than 24 million acres of land in the United States, and in Hawaii alone, the Army is steward for more than 165,000 acres. These lands possess an irreplaceable collection of natural and cultural resources. The Legacy Resource Management Program was established by the Defense Department in 1991 to identify, protect, and provide guidance for the management of significant biological, geophysical, cultural, and historical resources on or involving defense lands. Under the Legacy program, which has grown from \$10 million in funding in 1991 to about \$50 million in 1993, military installations throughout the United States are playing a part in demonstration projects to protect the nation's natural and cultural resources.

An inventory of biological resources at Schofield Barracks in cooperation with the Nature Conservancy is one such demonstration project. The goal of the project is to enhance protection of threatened and endangered and rare ecosystems. The protection will come from identifying the location and status of resources, assessing management issues, and implementing key management actions. "Inventories of Schofield Barracks, Makua Military Reservation, and Kapaemahu Training Area are nearing completion," said Mark Salley, environmental protection specialist at Schofield. According to Patrick Chung, agronomist and land manager, a three-part effort will help conserve natural resources in Hawaii. First, inventories are completed. Following this action, threats to natural resources are evaluated, and then a management plan is developed. Schofield Barracks is currently at this stage. Among the agencies that assisted with the inventory was Colorado State University. These scientists, botanists, and zoologists to help complete the enormous inventory task. "The plan will put us on a course to protect the species of plants and animals," Chung said. With the "biodiversity" of plant life in Hawaii, containing more endangered species than at any Army installation, the inventory participants in the Legacy program have a lot on their hands full. "We are trying to find the best ways to protect the plants and animals," Salley said.

## Storage-tank removal unearths remnants of Spanish garrison

Archaeologists find 200-year-old artifacts at Presidio of S.F.

PRESIDIO OF SAN FRANCISCO, Calif.—U.S. Army Corps of Engineers

archaeologists have made a major discovery on the Presidio of San Francisco. The remains of a Spanish military building, discovered during an underground-storage-tank removal, could mark the very beginning of Spanish presence in the San Francisco Bay area. Archaeologist Vance Benke, of Woodward-Clyde Consultants, said the stone wall appears to be from the era of the founding of Presidio in the late 1700s. Artifacts, including part of the rock foundations of the building, adobe bricks, dishes, and tools used by Spanish troops, are at least 200 years old.

The original Presidio was thought to have been approximately 100 yards square. This land is just outside the area where the original Presidio was built. Benke thinks the building might have been a case-

ment, or building used to store gunpowder and munitions.

More extensive study will be required to determine the extent of the wall. Once this is done, it may be possible to define even better how the original Presidio looked.

The discovery was made in the back yard of a set of family housing quarters on Funston Avenue inside the Presidio. The 3-story, 3-avenue family housing buildings are historic as well, having been constructed during the 1860s and 1870s. The excavation that led to the wall's discovery is part of ongoing environmental projects conducted by the Army prior to turning the Presidio over to the Golden Gate National Recreation Area. The work also includes extensive repairs to the Presidio's infrastructure, including replacement of sewer lines. During some of these excavations, pieces of broken dishes from various periods in the Presidio's history have been discovered.

Each of these discoveries is being documented, catalogued, and preserved as part of a significant period in California and American history.

## Fort Belvoir commander signs plan to manage wildlife 'corridor'

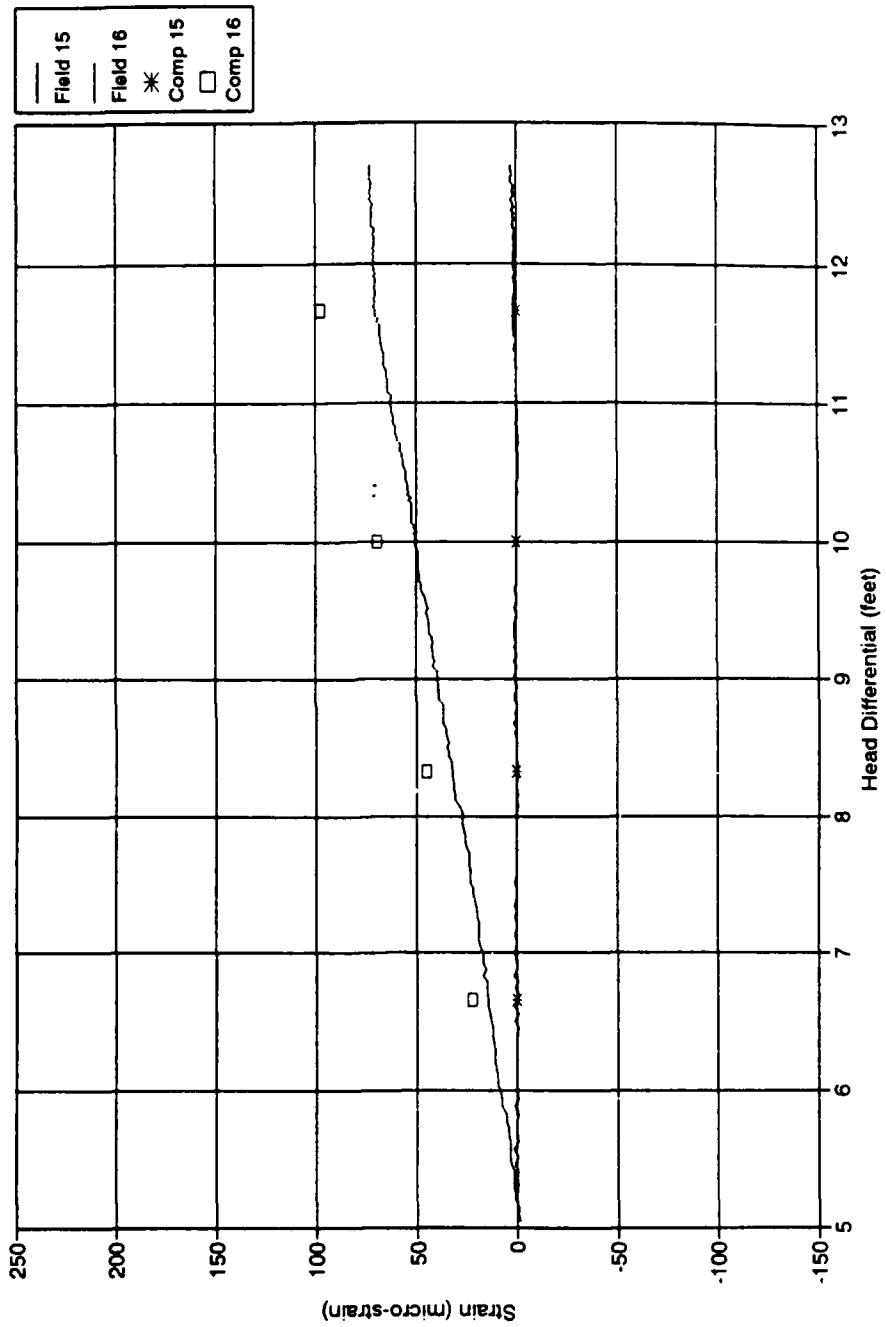
Rebecca Wriggle

naturally existing regional wildlife corridor that extends roughly from Fairfax

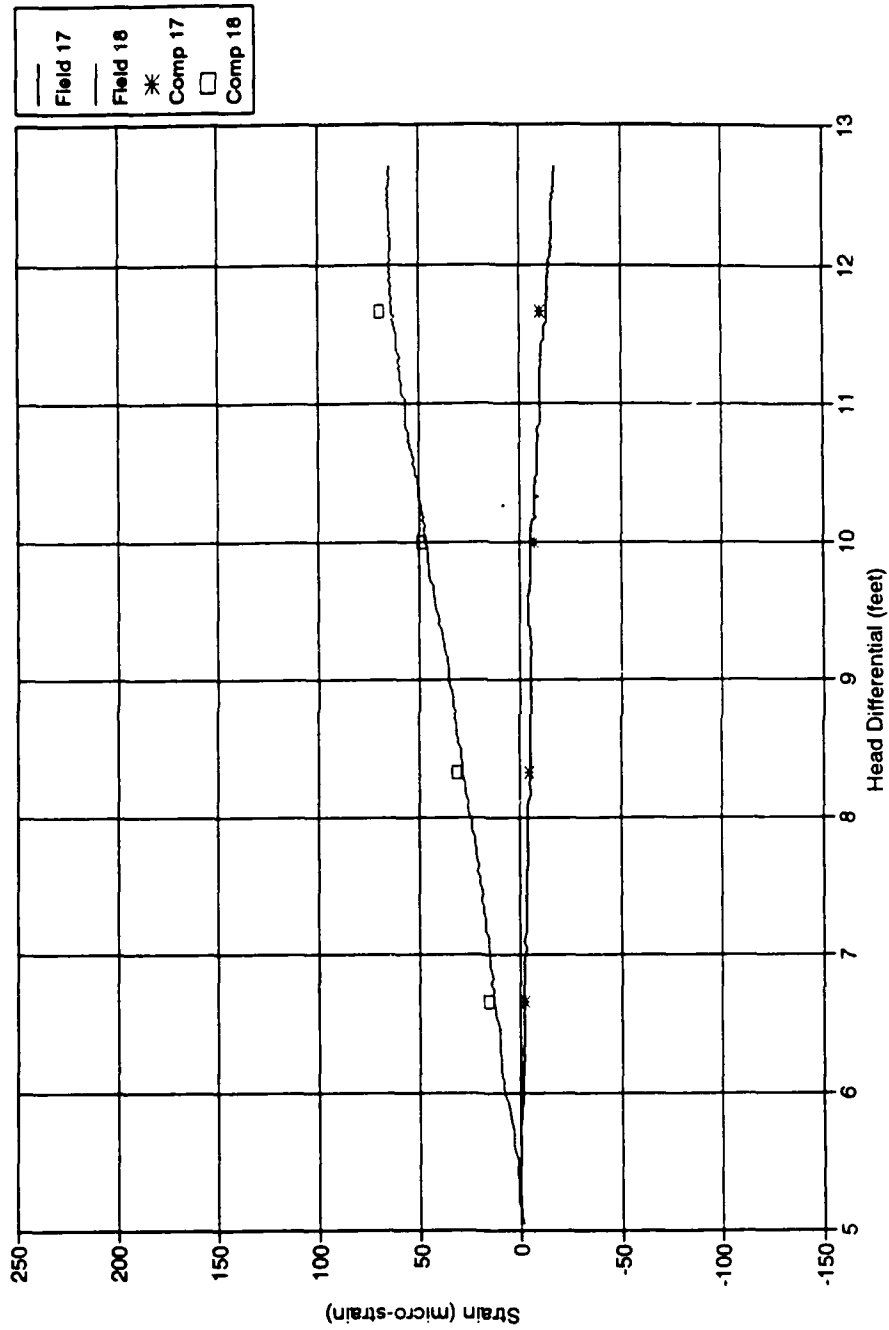
"The refuges and connecting corridor taken together total approximately 2,100

explaining how Fort Belvoir, as an open most allows outside visitors such as the

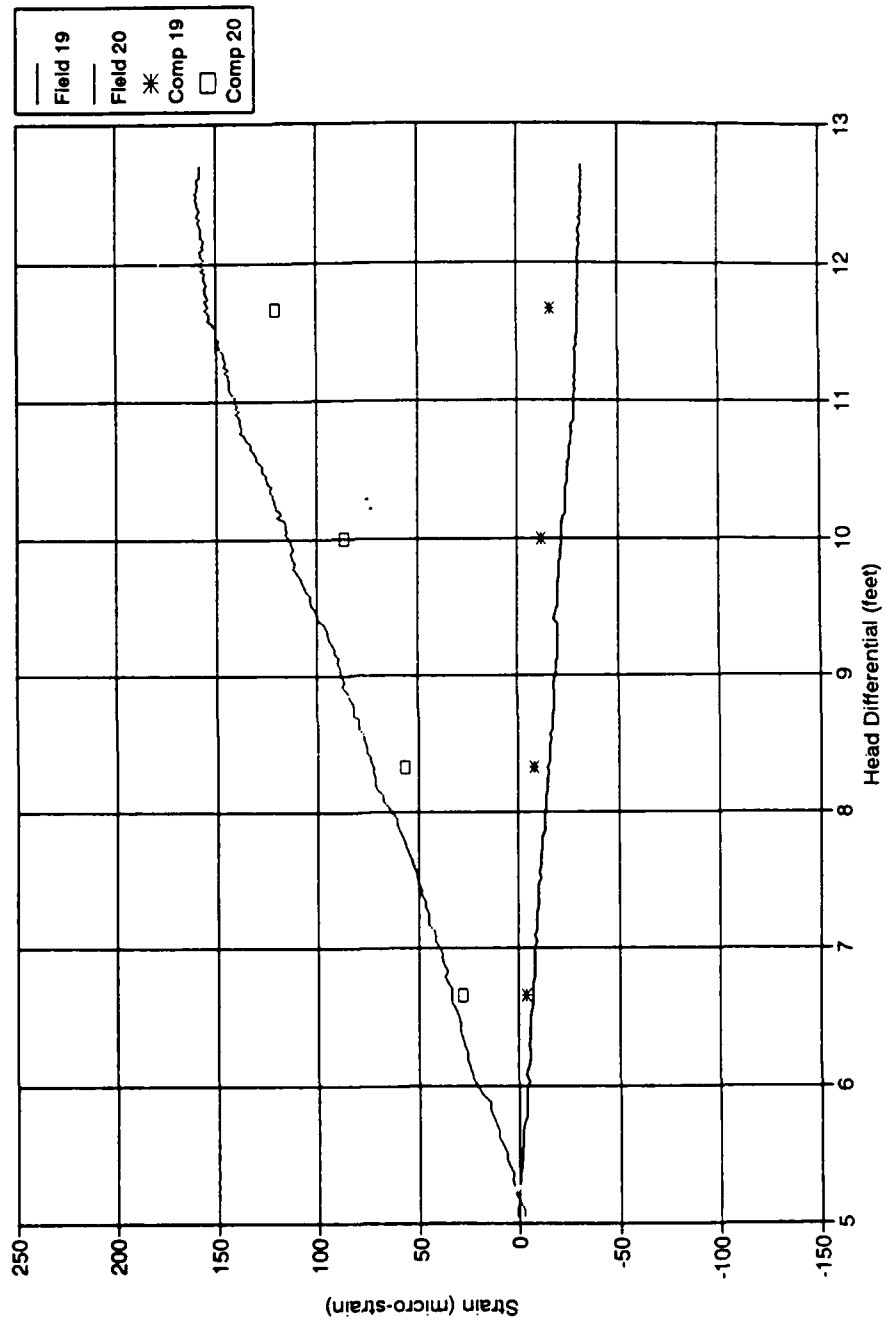
Emsworth: Strain vs. Head Differential  
Channels 15 & 16 - Diagonals in Bay 2



Emsworth: Strain vs. Head Differential  
Channels 17 & 18 - Miter Girder (Top)

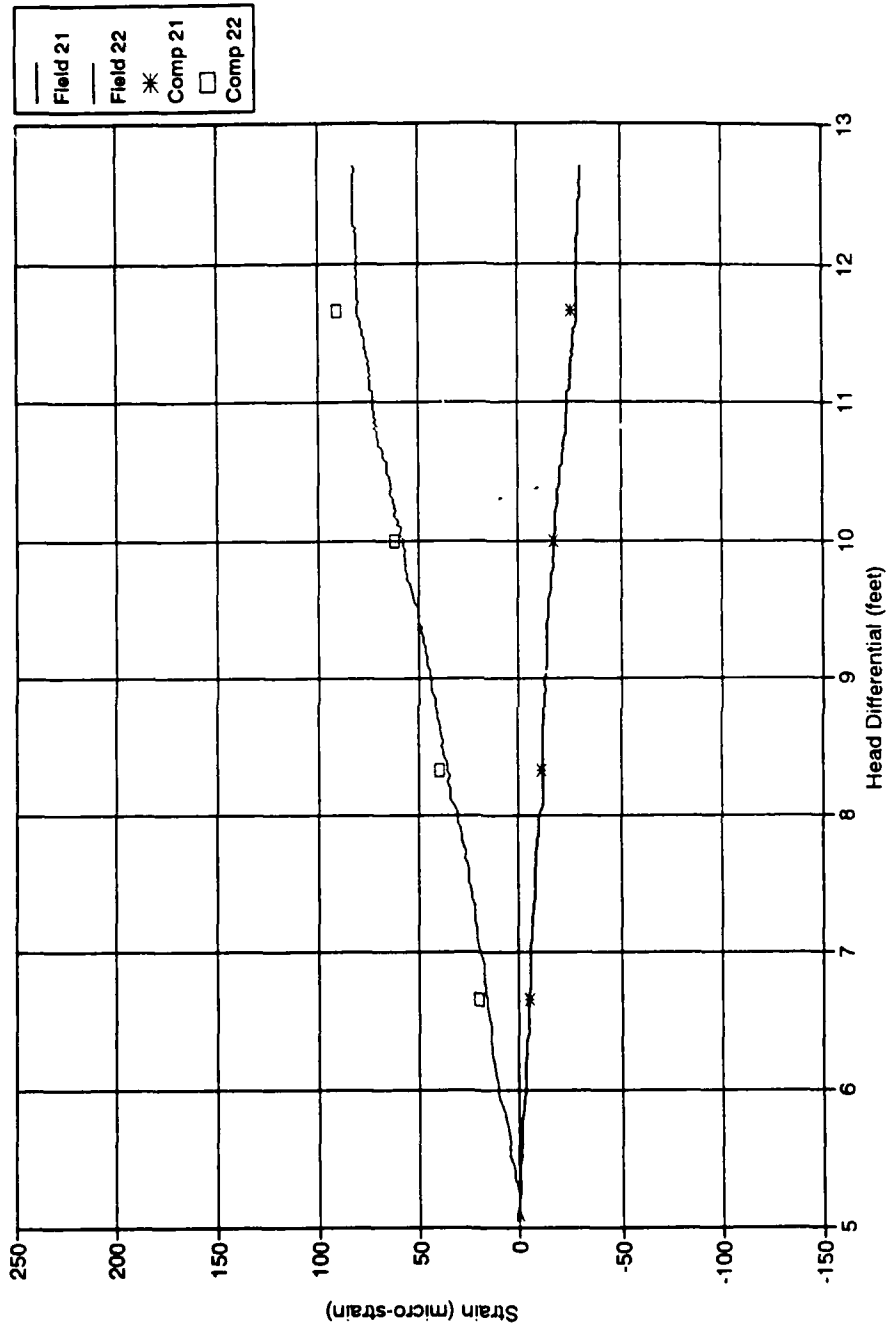


Emsworth: Strain vs. Head Differential  
Channels 19 & 20 - Miter Girder (lower)

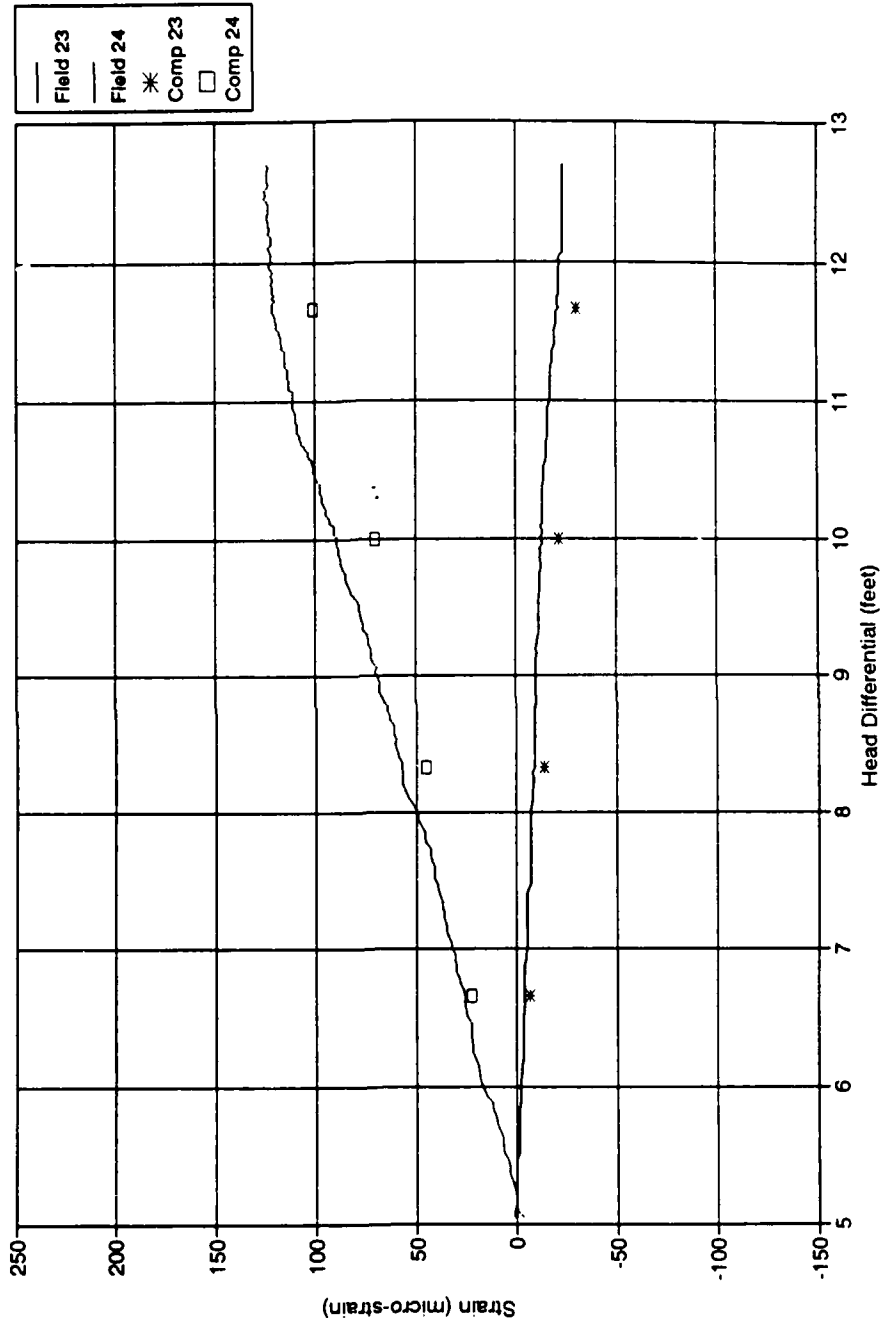




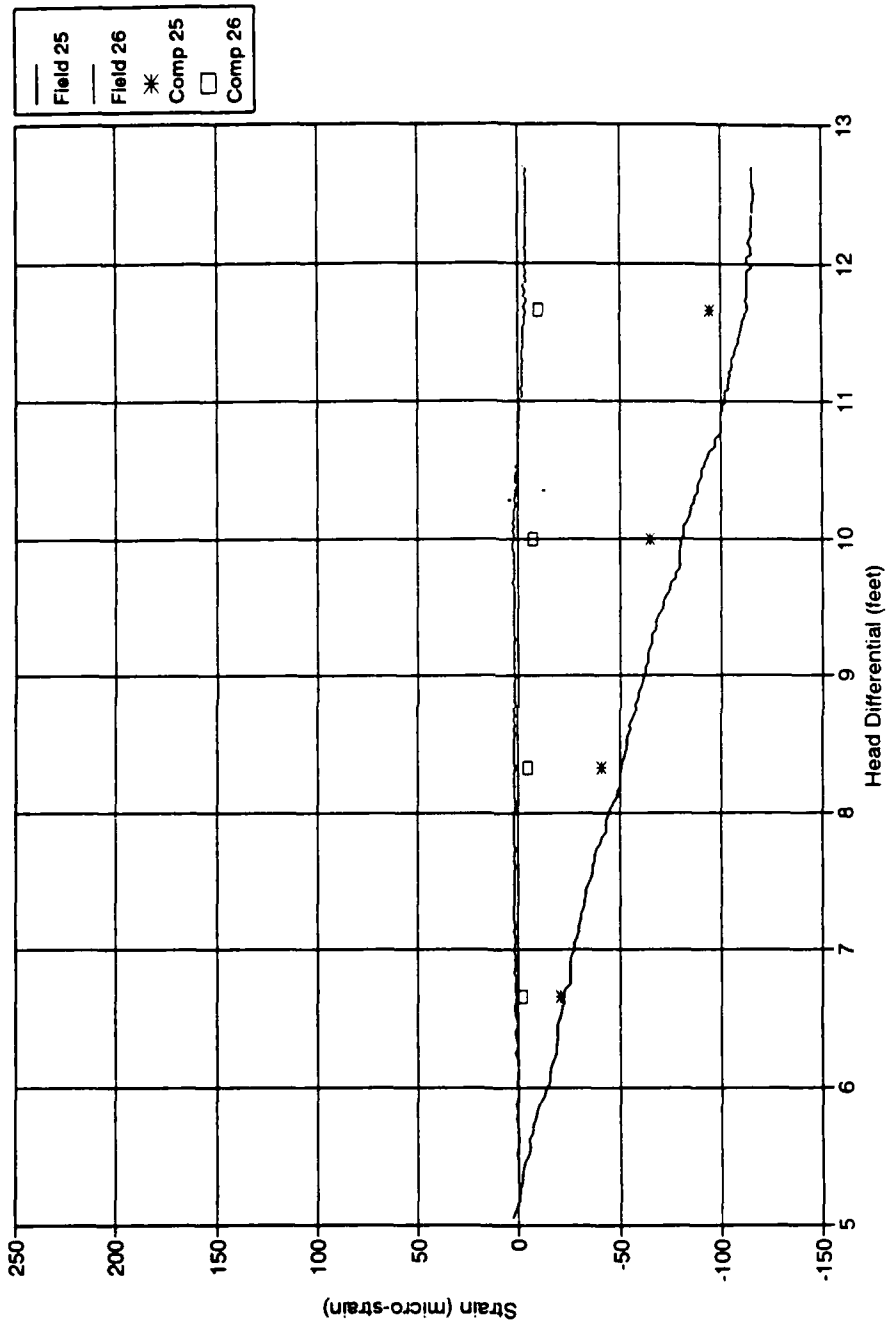
Emsworth: Strain vs. Head Differential  
Channels 21 & 22 - V. Beam 5 (Top)



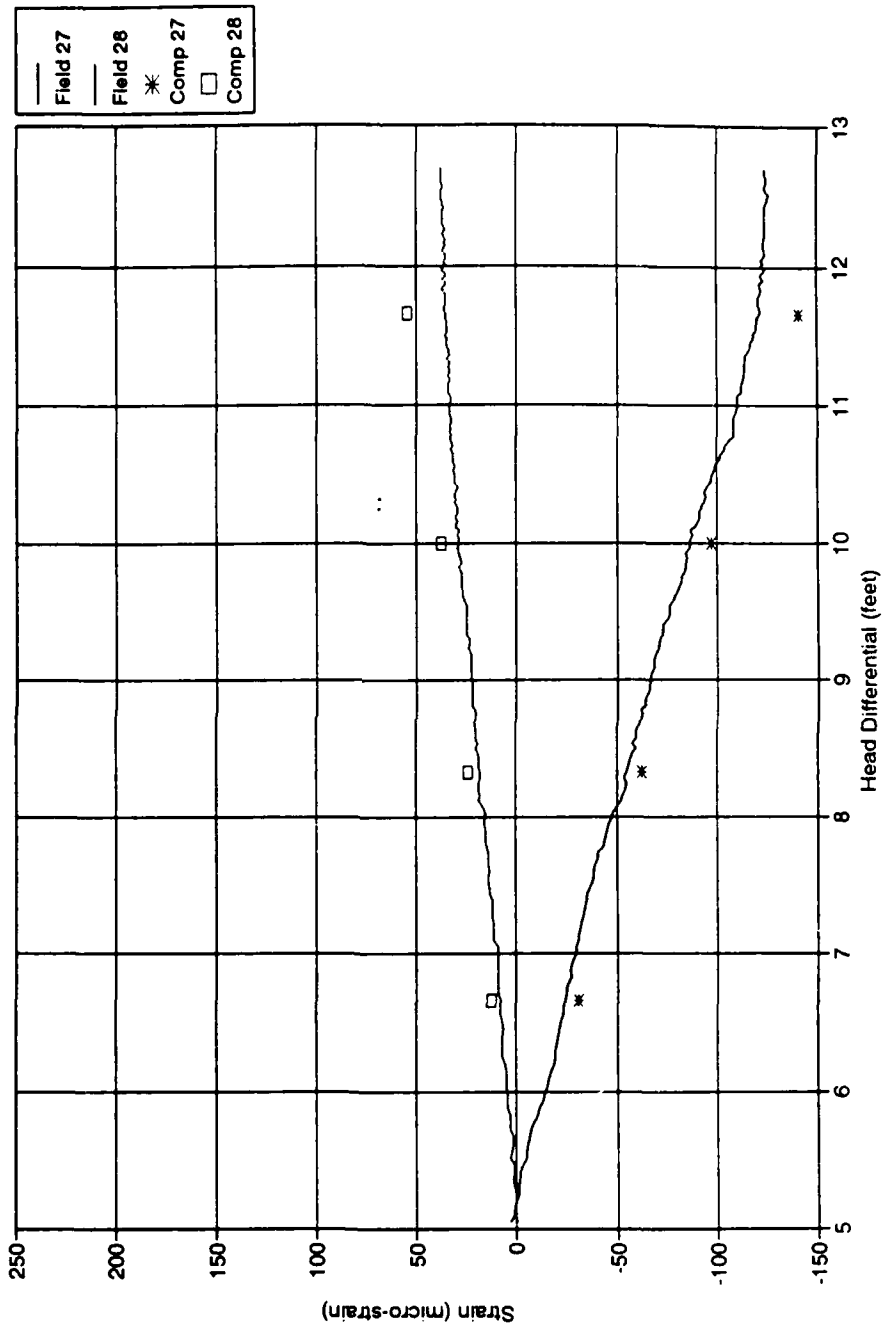
Emsworth: Strain vs. Head Differential  
Channels 23 & 24 - V. Girder (Top)



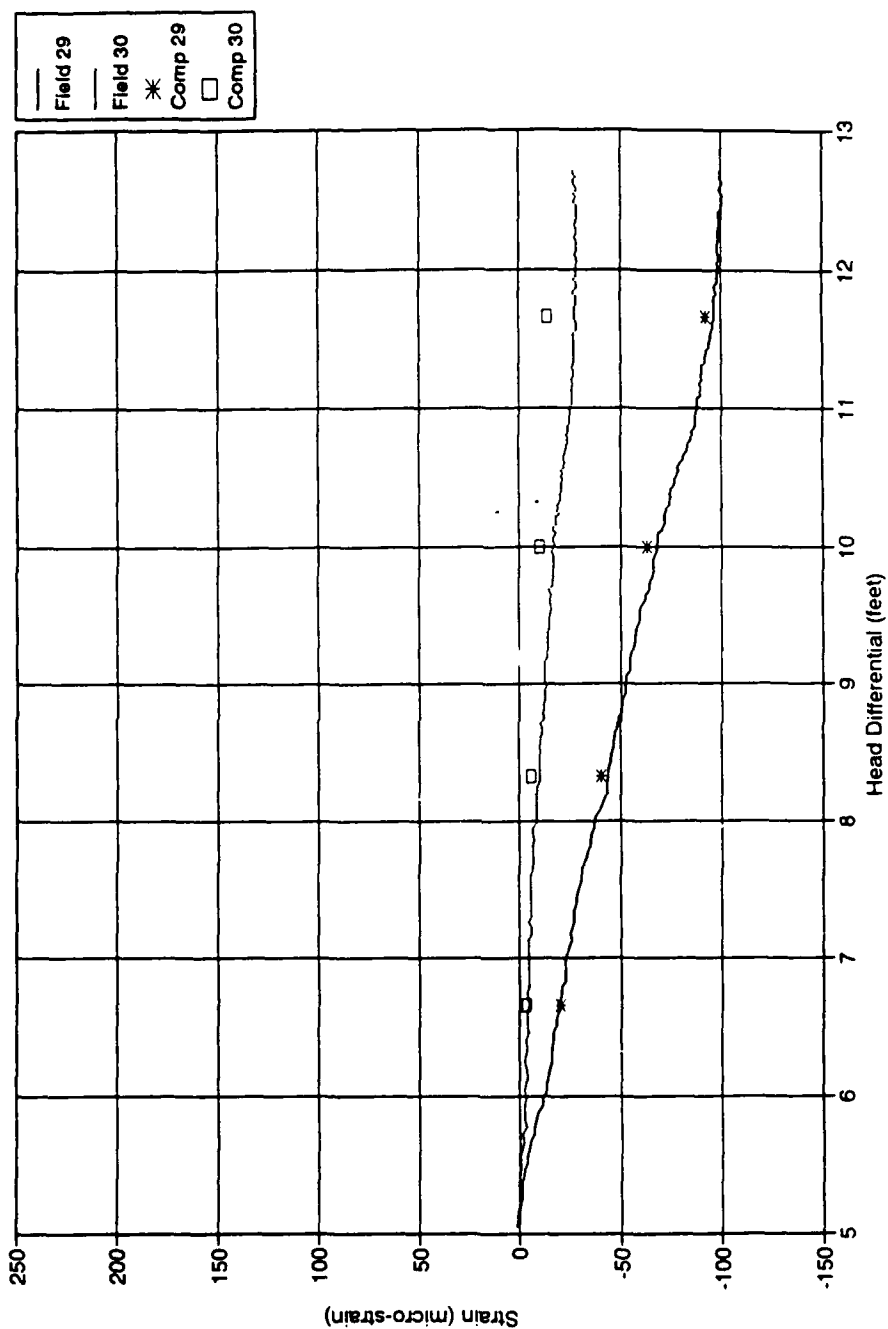
Emsworth: Strain vs. Head Differential  
Channels 25 & 26 - Top Girder (M. End)



Emsworth: Strain vs. Head Differential  
Channels 27 & 28 - Top Girder (Mid)



Emsworth: Strain vs. Head Differential  
Channels 29 & 30 - Top Girder (Q. End)

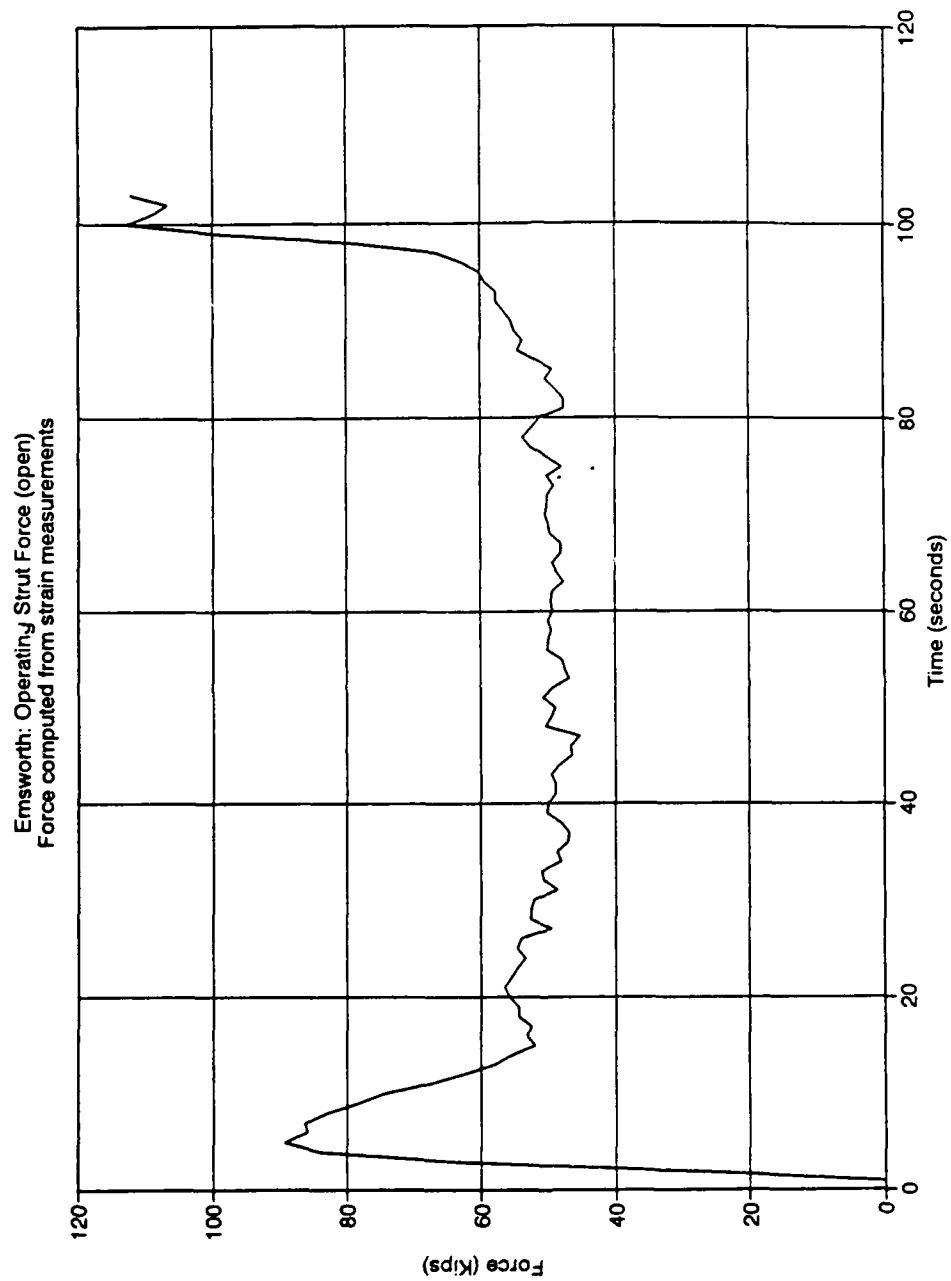


## Appendix D

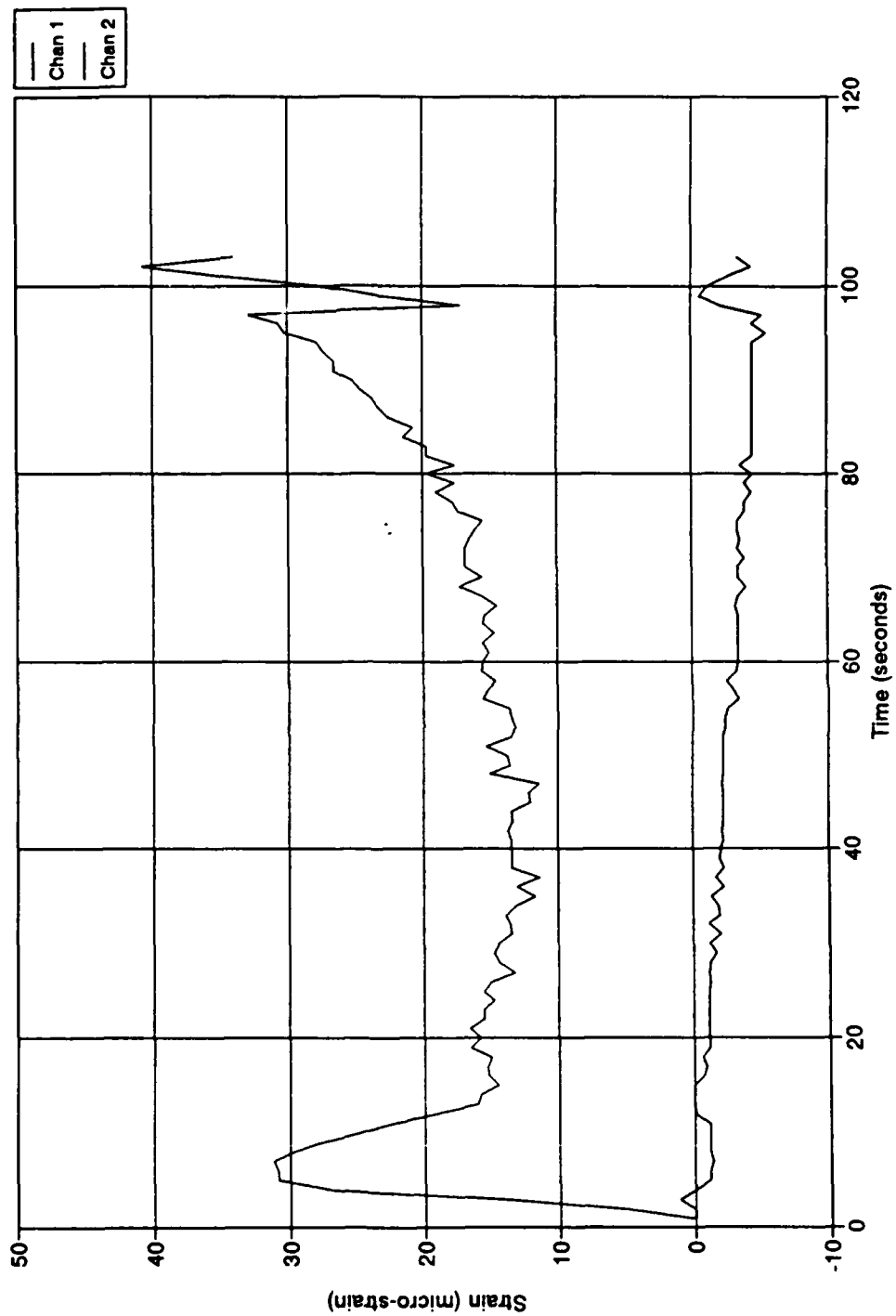
# Gate Operation Measurements (Gate Opening)

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This appendix presents the results for the gate operation test in which the gate leaf was opened (from miter position to recess position). The force exerted by the operating strut is presented in Figure D1, and the remaining figures contain graphs of strain histories as a function of testing time for each strain transducer (the figure legends describe data for each transducer channel as Chan). The force in the operating strut was calculated by taking the average strain output of the two attached transducers, multiplying the quantity by the product of Young's modulus and the cross-sectional area. It was assumed that the operating strut was made up of a W8 × 40 and had a cross-sectional area of 11.7 sq in. Only the member depth was measured in the field; therefore, the size of the operating strut should be verified.

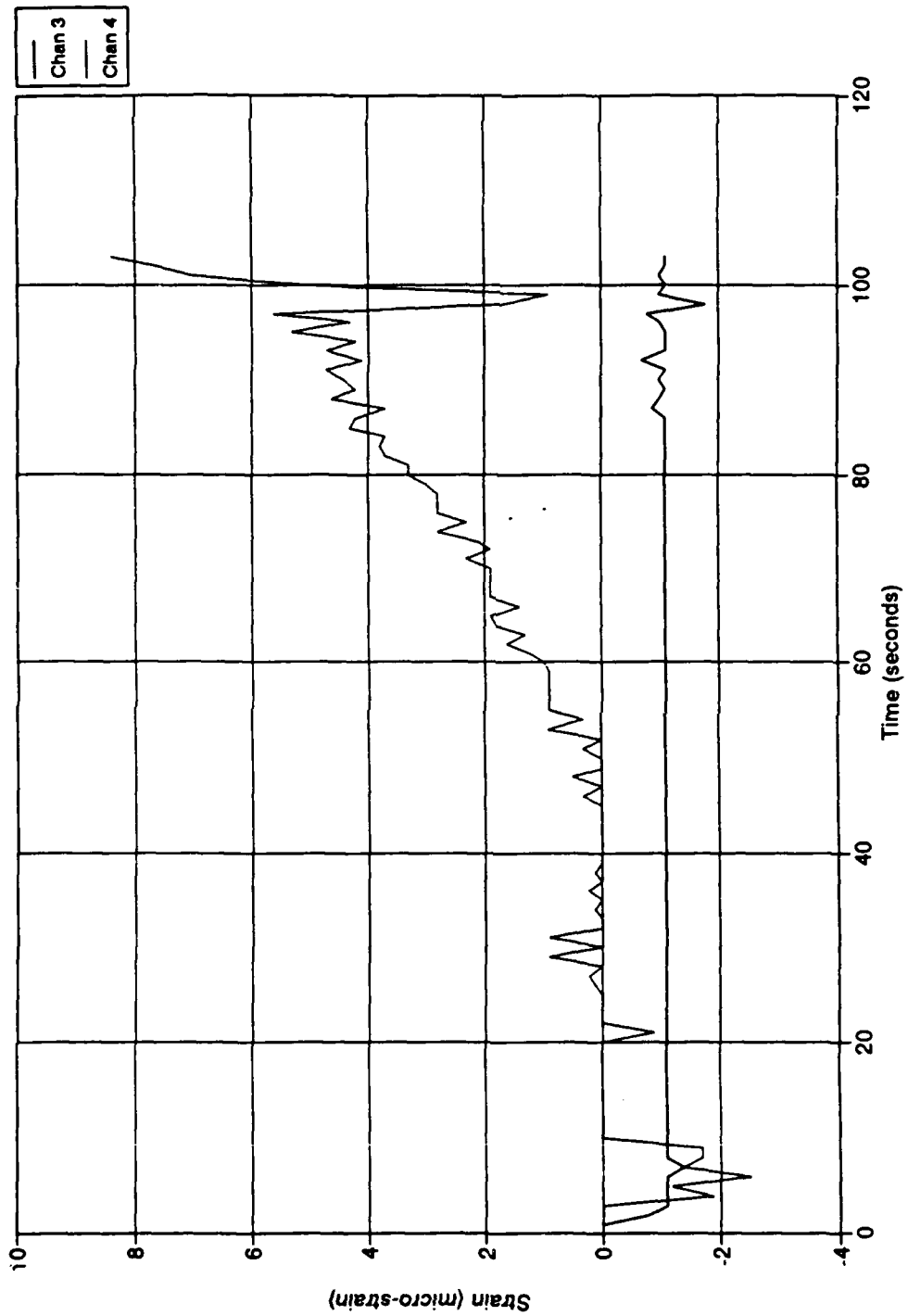


Emsworth: Strain History (Gate Opening)  
Channels 1 & 2 - Quoin Girder

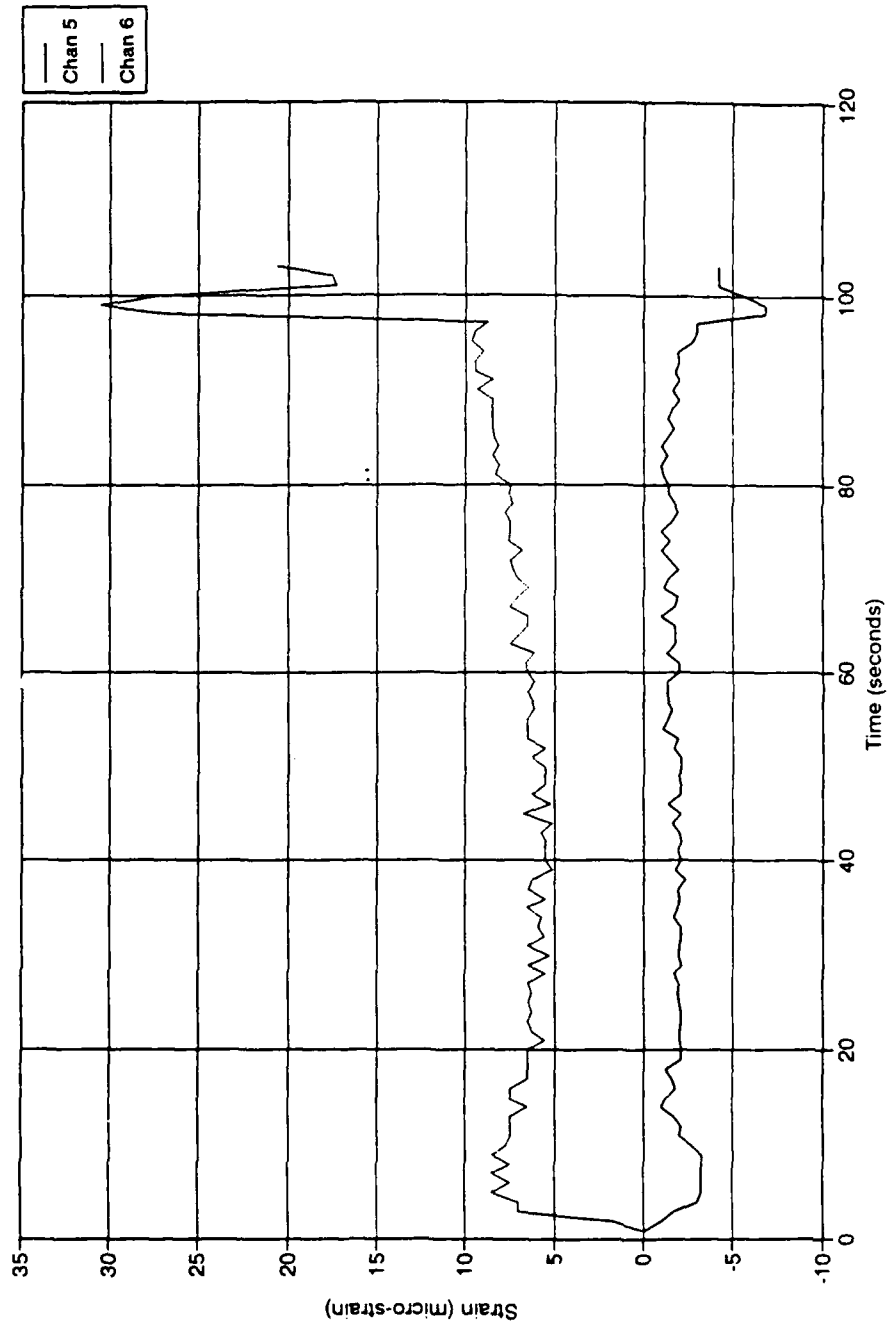




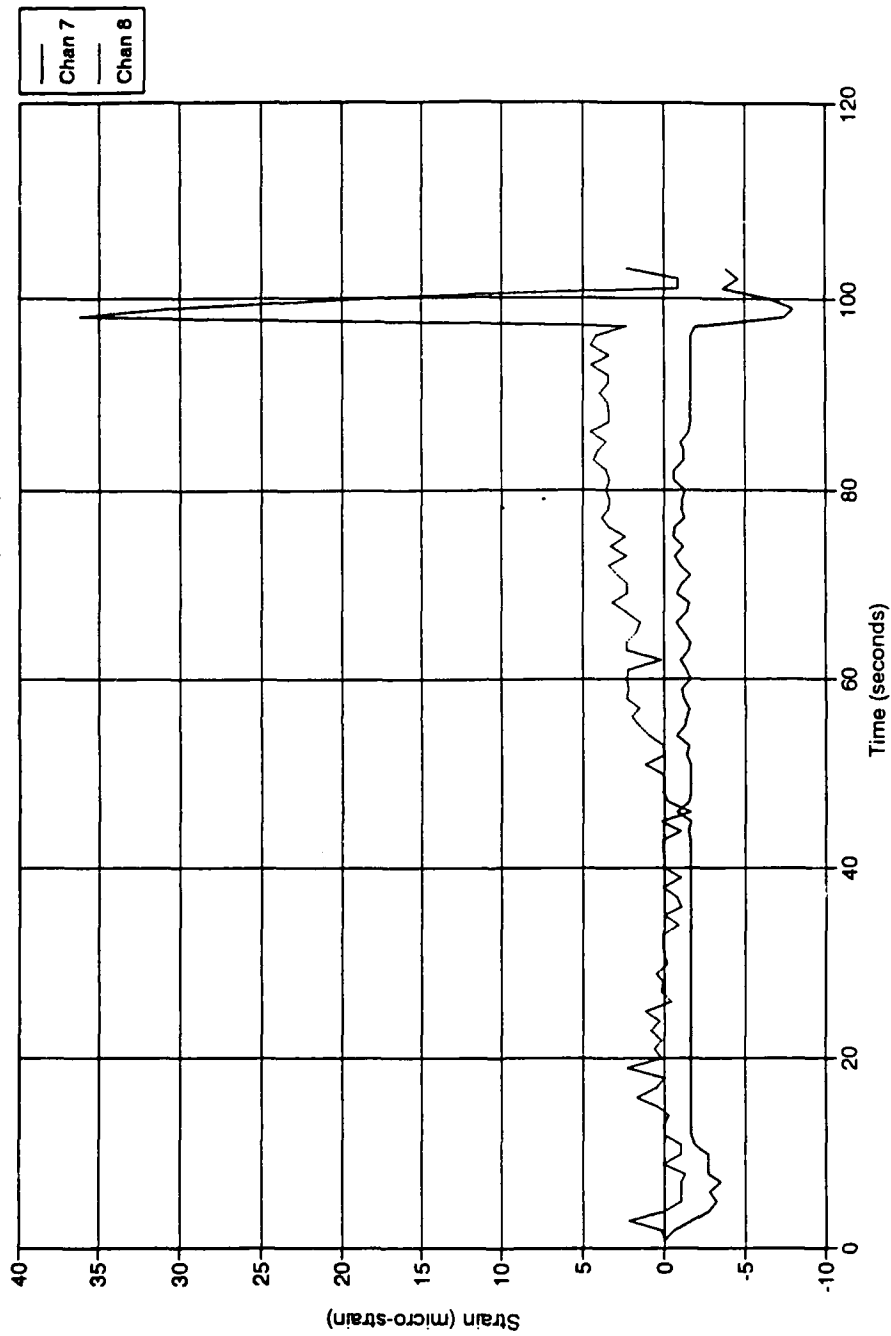
Emsworth: Strain History (Gate Opening)  
Channels 3 & 4 - Vertical Beam 3



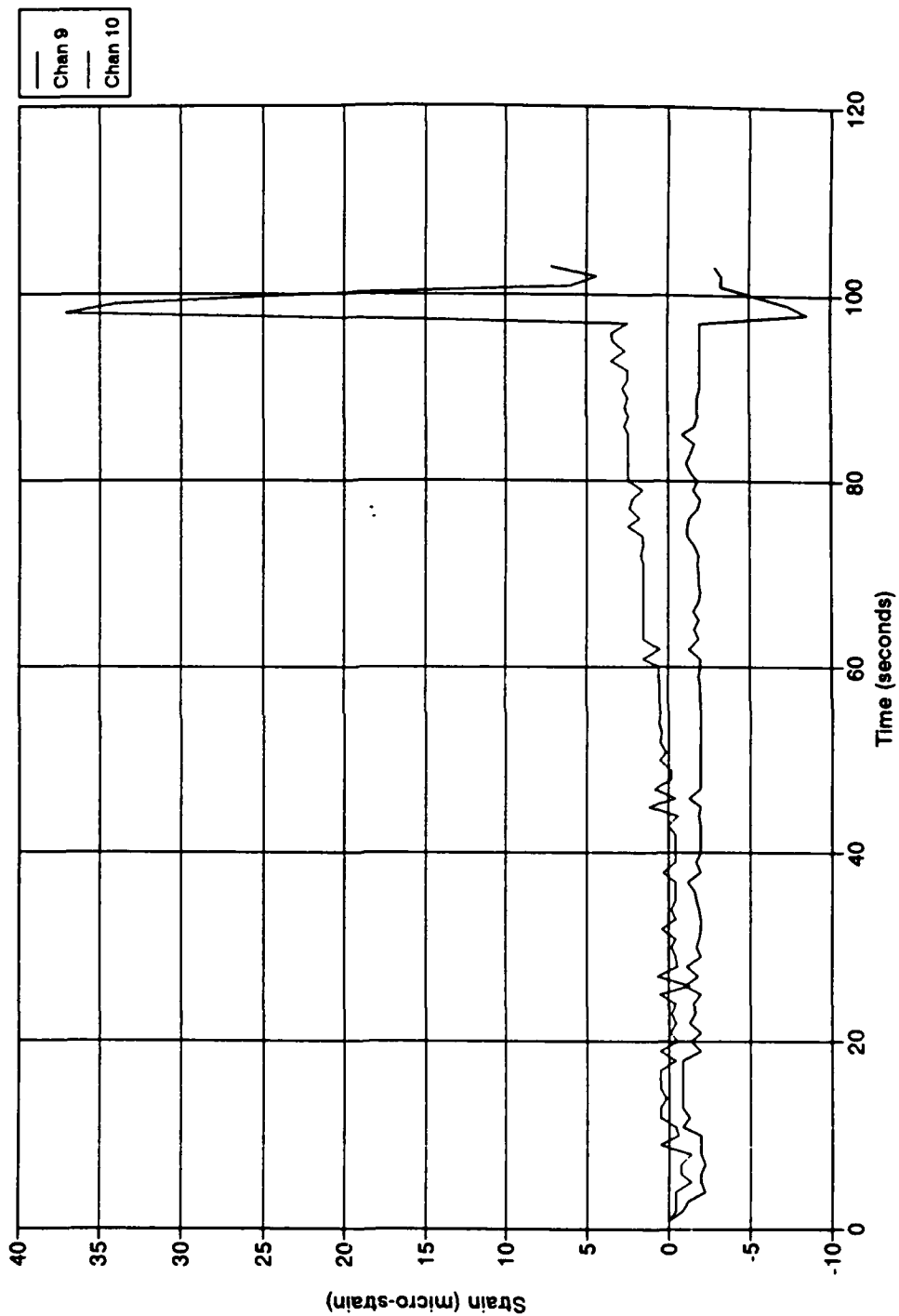
Emsworth: Strain History (Gate Opening)  
Channels 5 & 6 - Vertical Beam 5



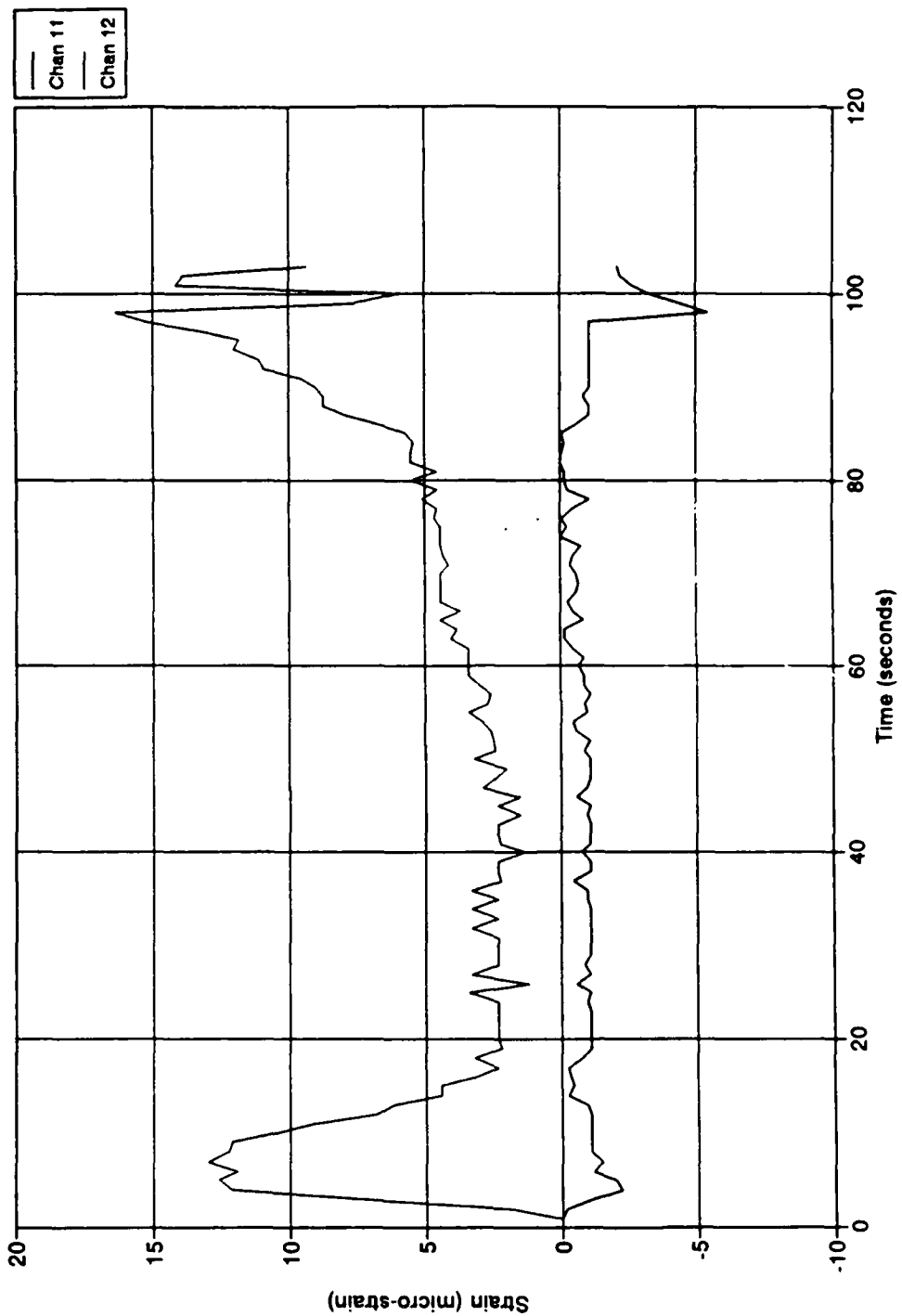
Emsworth: Strain History (Gate Opening)  
Channels 7 & 8: Vertical Girder (lower)



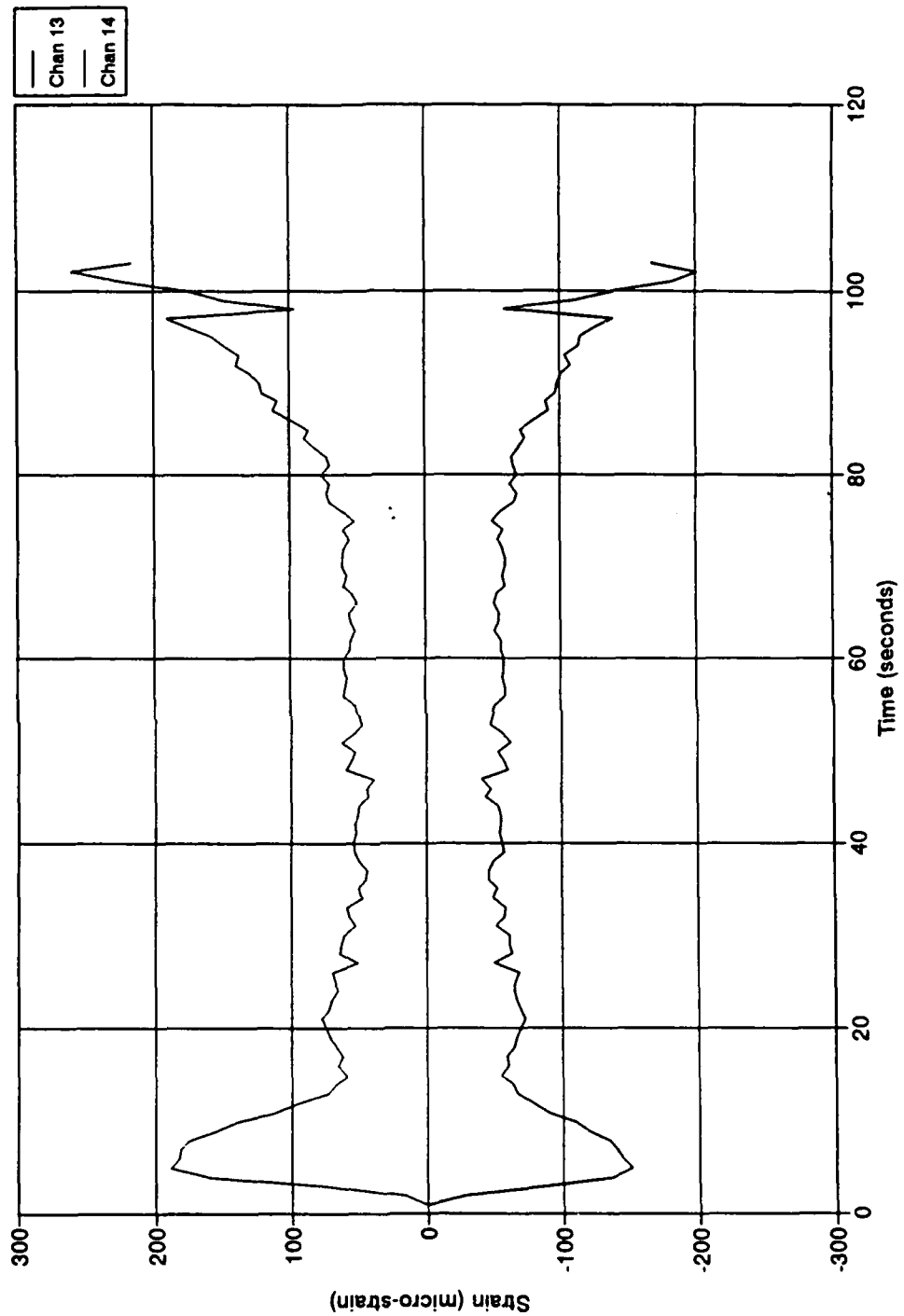
Emsworth: Strain History (Gate Opening)  
Channels 9 & 10 - Vertical Beam 6



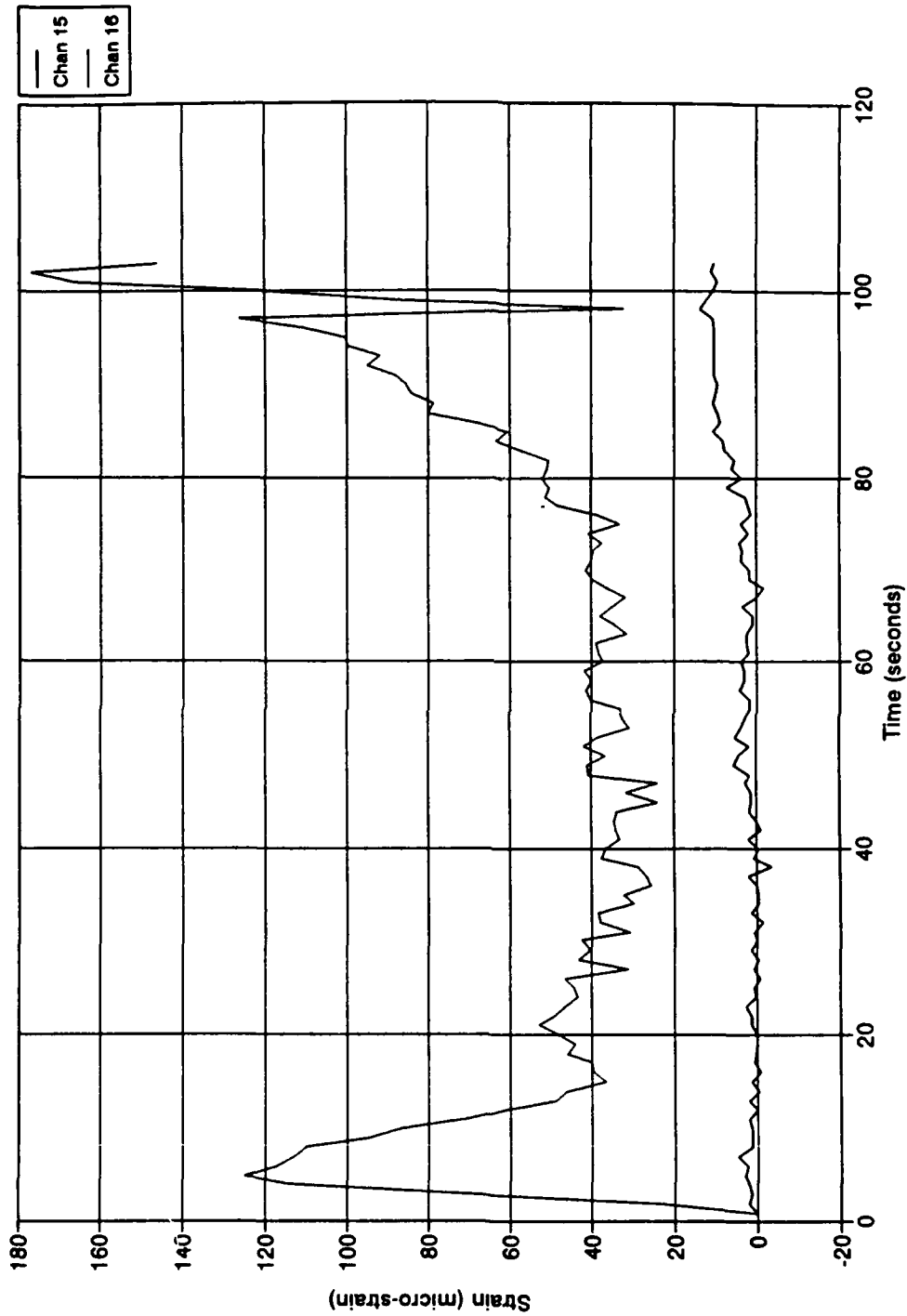
Emsworth: Strain History (Gate Opening)  
Channels 11 & 12 - Vertical Beam 8

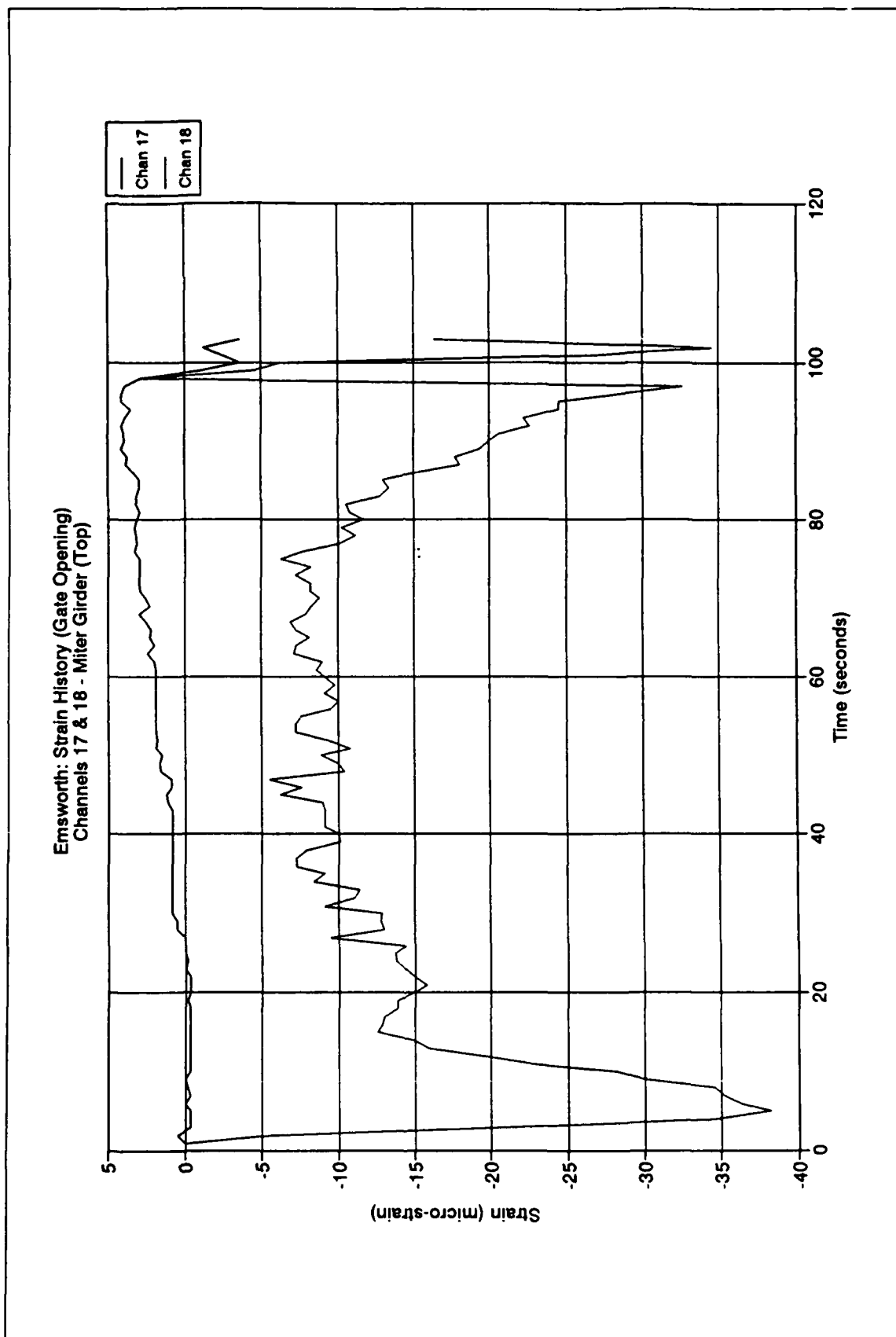


Emsworth: Strain History (Gate Opening)  
Channels 13 & 14 - Diagonals 1 and 2



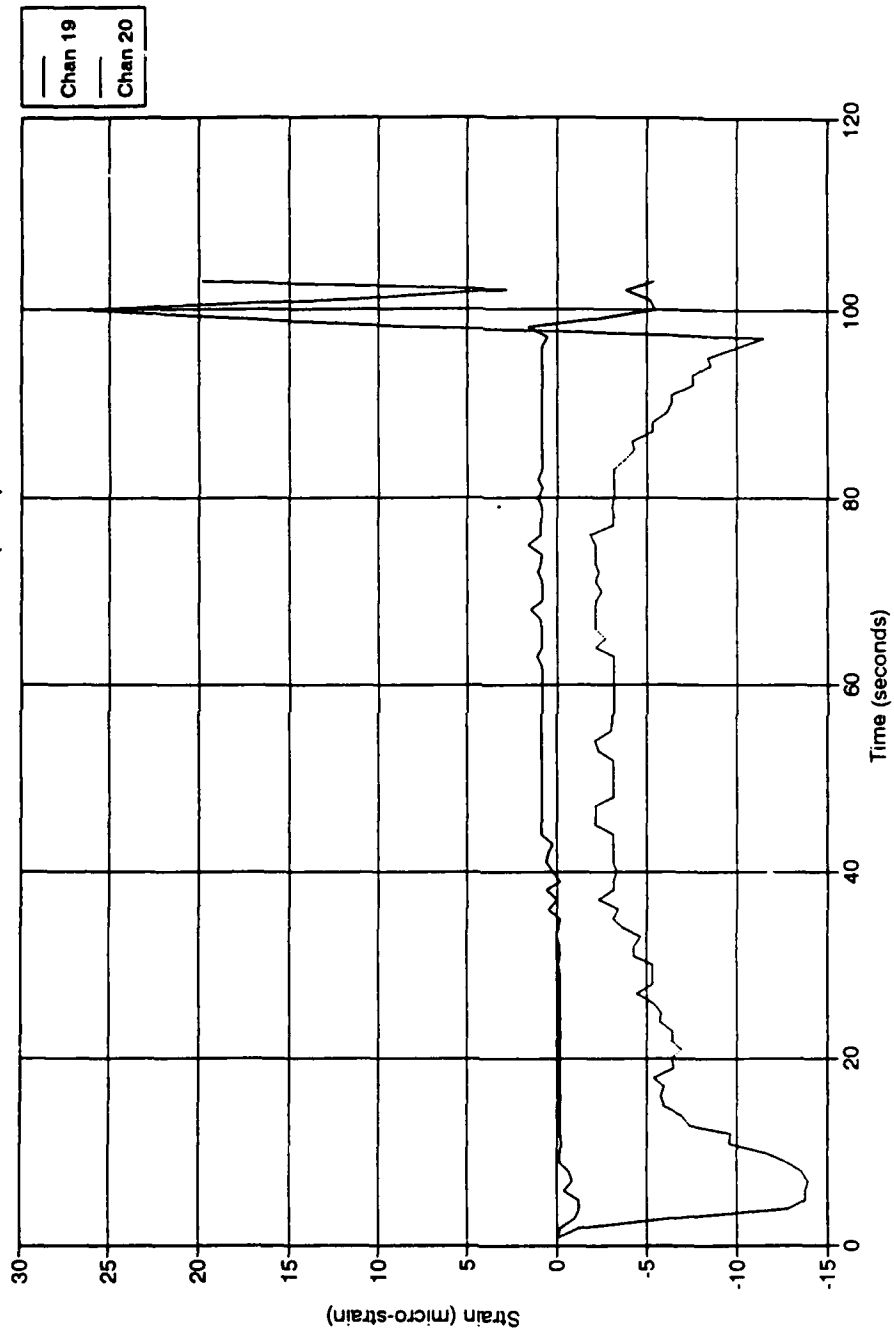
Emsworth: Strain History (Gate Opening)  
Channels 15 & 16 - Diagonals 3 and 4



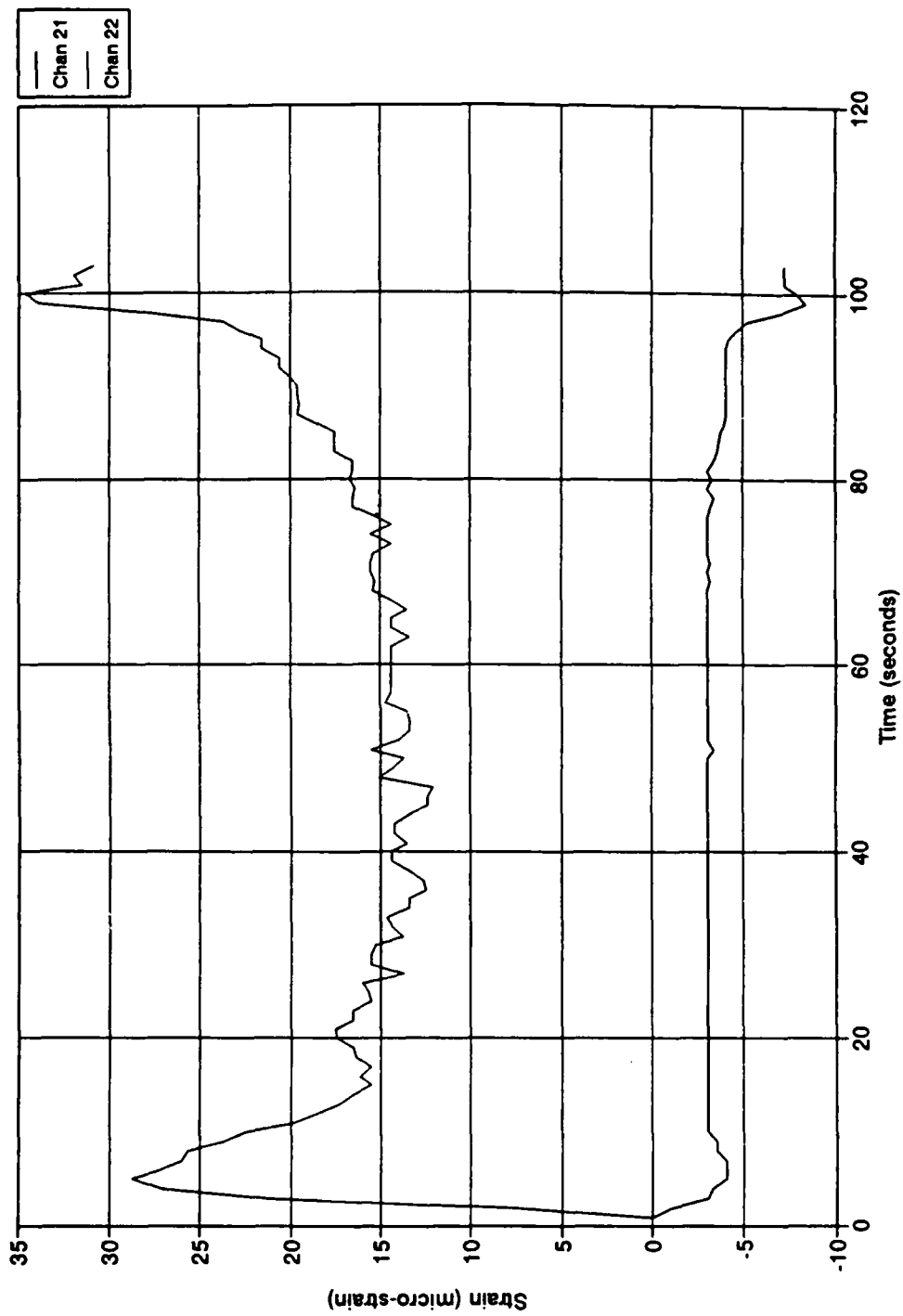




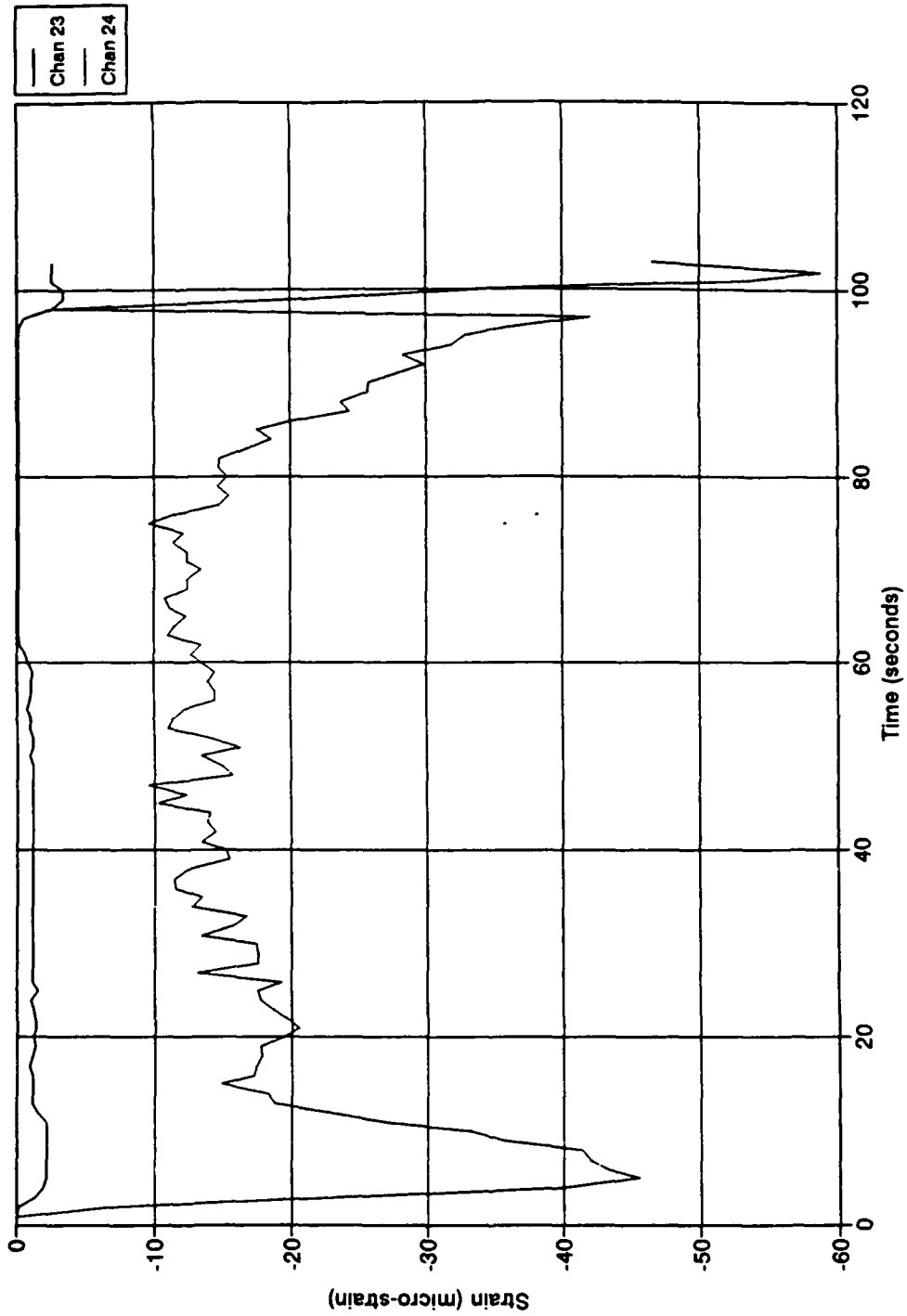
Emsworth: Strain History (Gate Opening)  
Channels 19 & 20 - Miter Girder (lower)



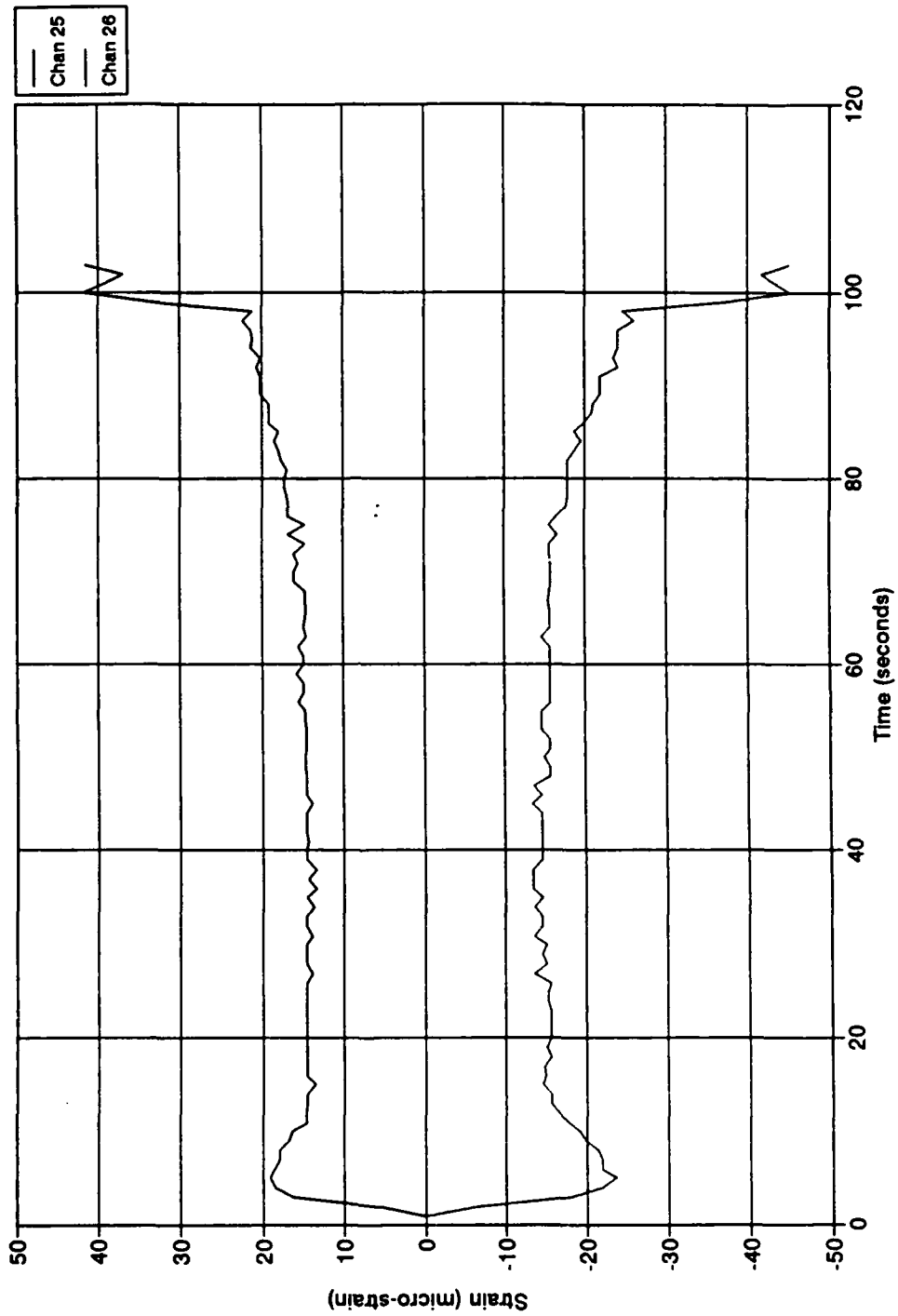
Emsworth: Strain History (Gate Opening)  
Channels 21 & 22: Vertical Beam 5 (top)



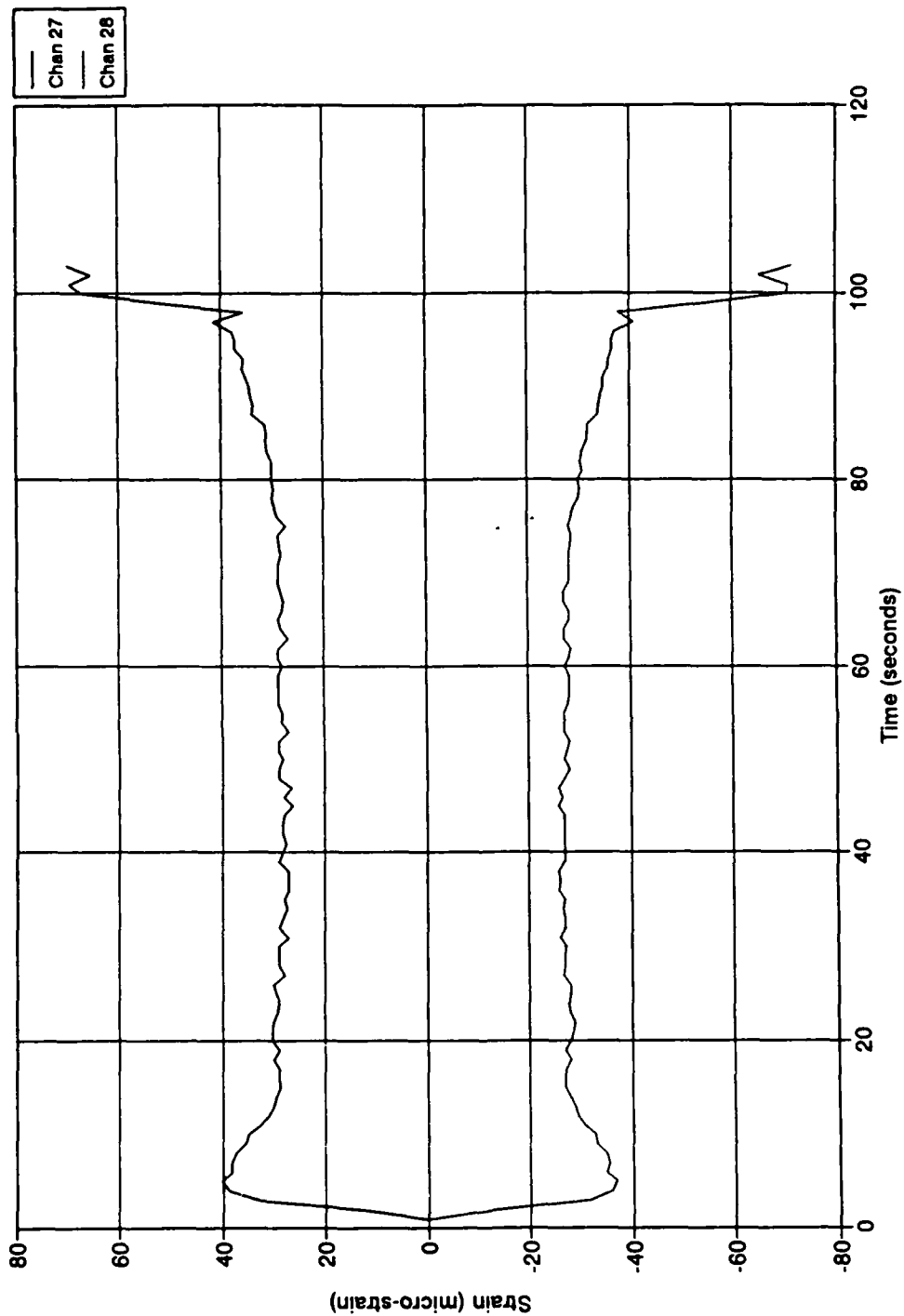
Emsworth: Strain History (Gate Opening)  
Channels 23 & 24: Vertical Girder (top)



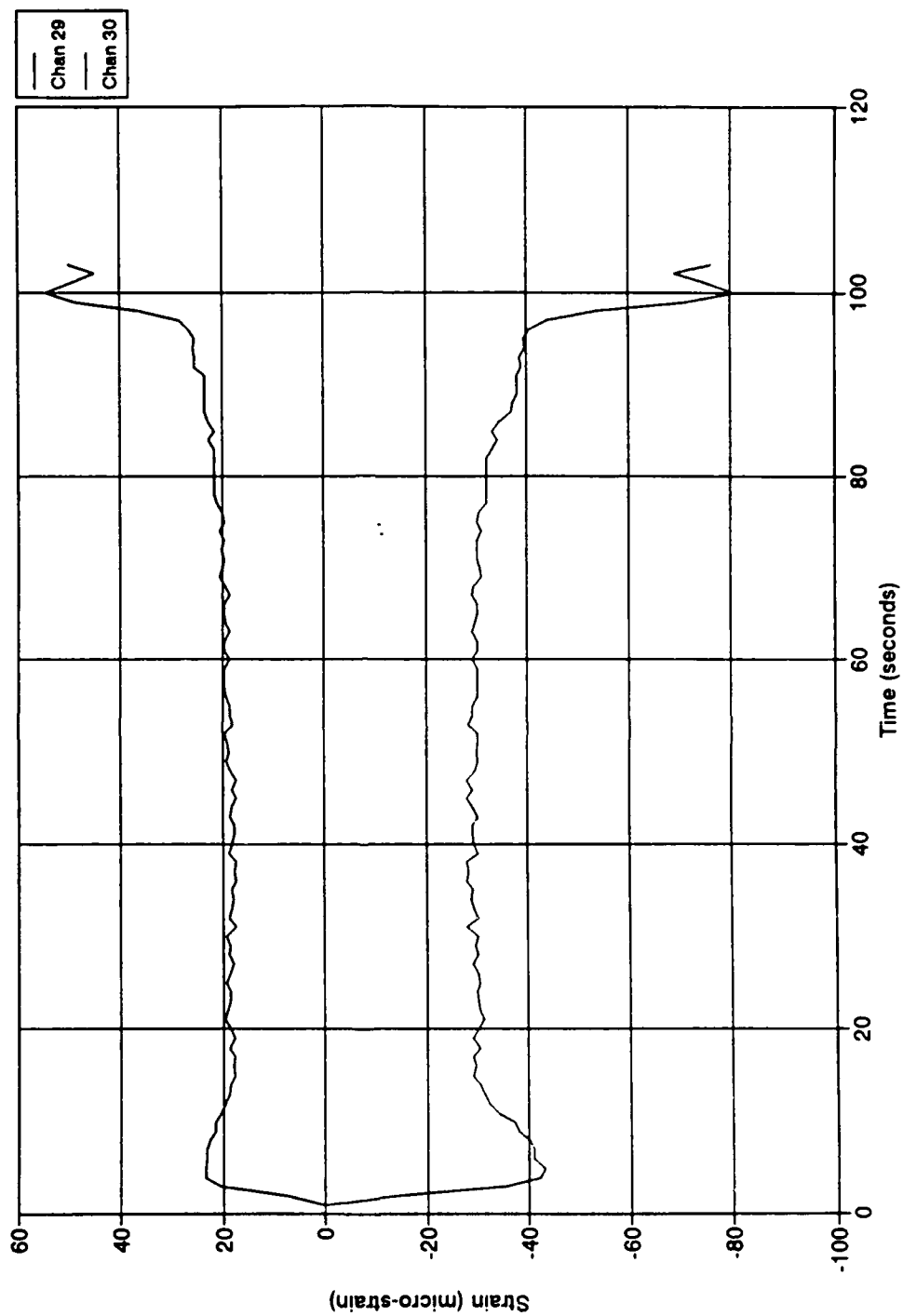
Emsworth: Strain History (Gate Opening)  
Channels 25 & 26: Top Girder (Mtr. End)

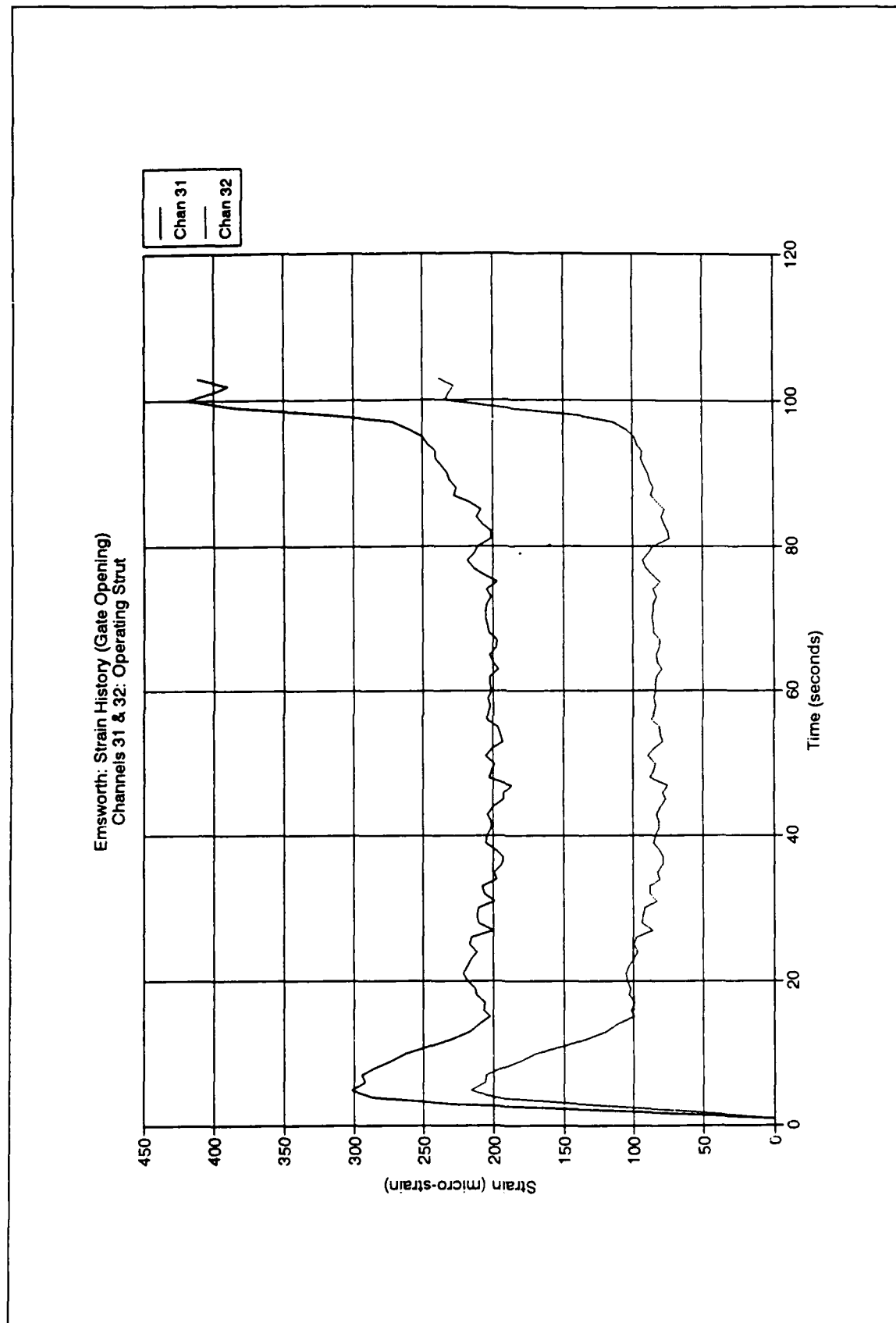


Emsworth: Strain History (Gate Opening)  
Channels 27 & 28: Top Girder (Mid)



Emsworth: Strain History (Gate Opening)  
Channels 29 & 30: Top Girder (Quoin)





## Appendix E

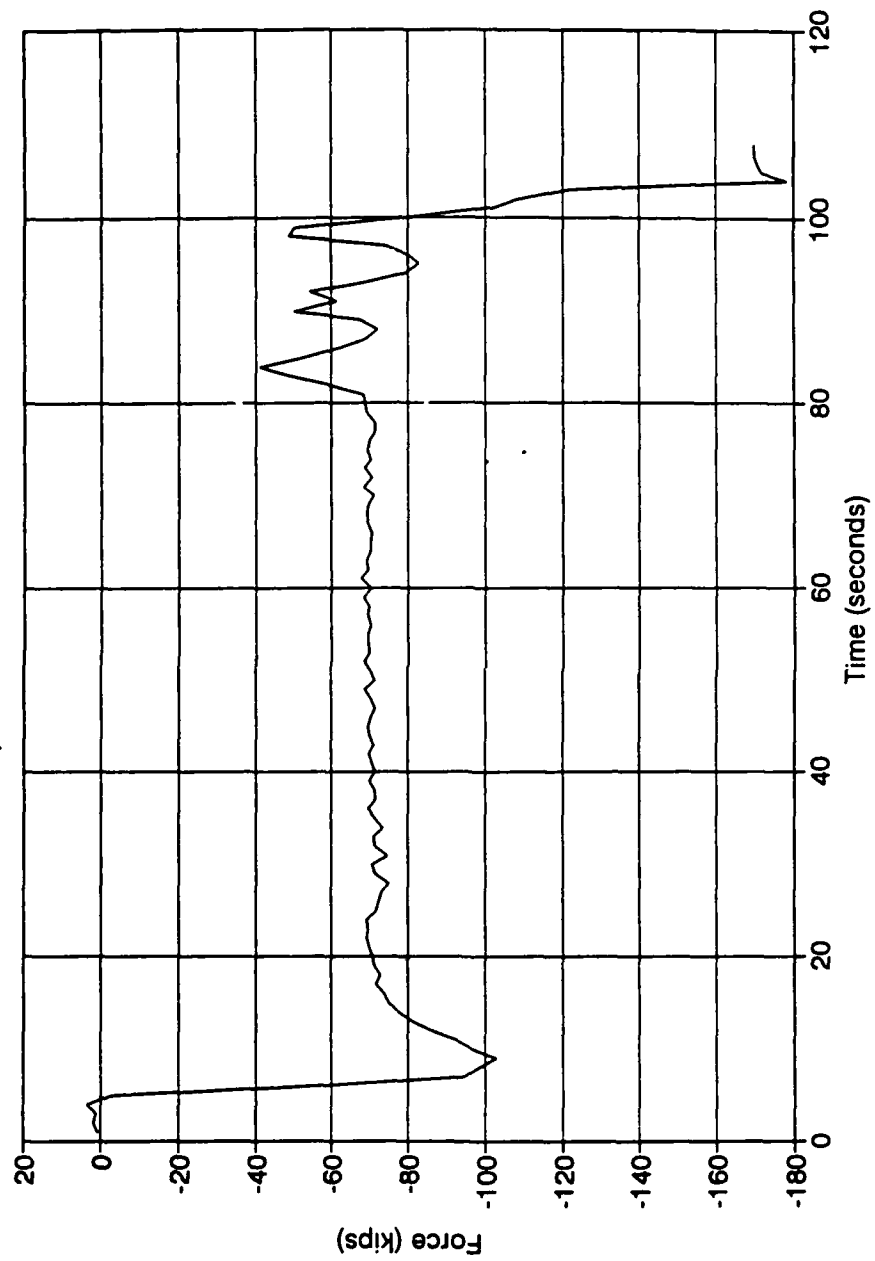
# Gate Operation Measurements (Gate Closing)

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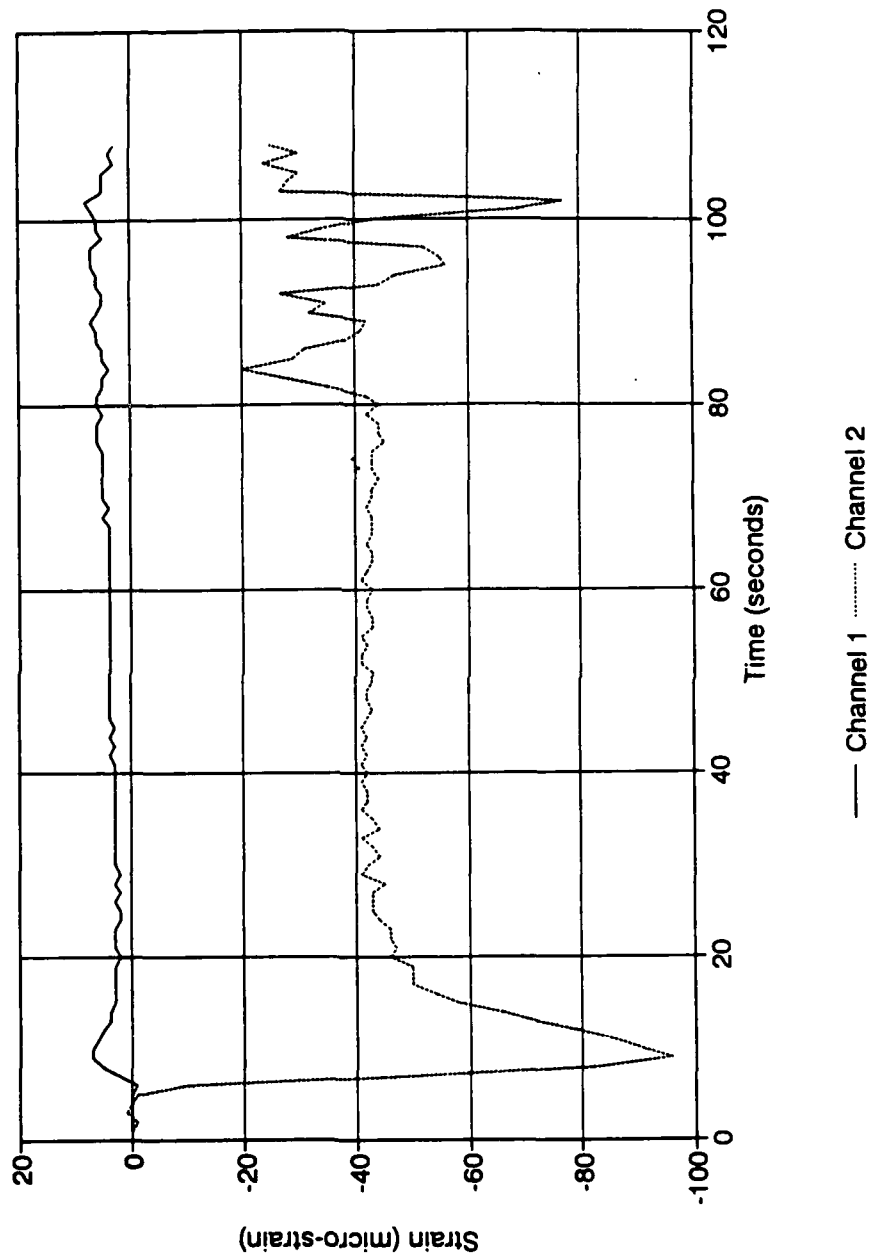
This appendix presents the results for the gate operation test in which the gate leaf was closed (from recess position to miter position). The force exerted by the operating strut is presented in Figure E1, and the remaining figures contain graphs of strain histories as a function of testing time for each strain transducer (the figure legends describe data for each transducer channel as Channel). The force in the operating strut was calculated by taking the average strain output of the two attached transducers, multiplying the quantity by the product of Young's modulus and the cross-sectional area. It was assumed that the operating strut was made up of a W8  $\times$  40 and had a cross-sectional area of 11.7 sq in. Only the member depth was measured in the field; therefore, the size of the operating strut should be verified.



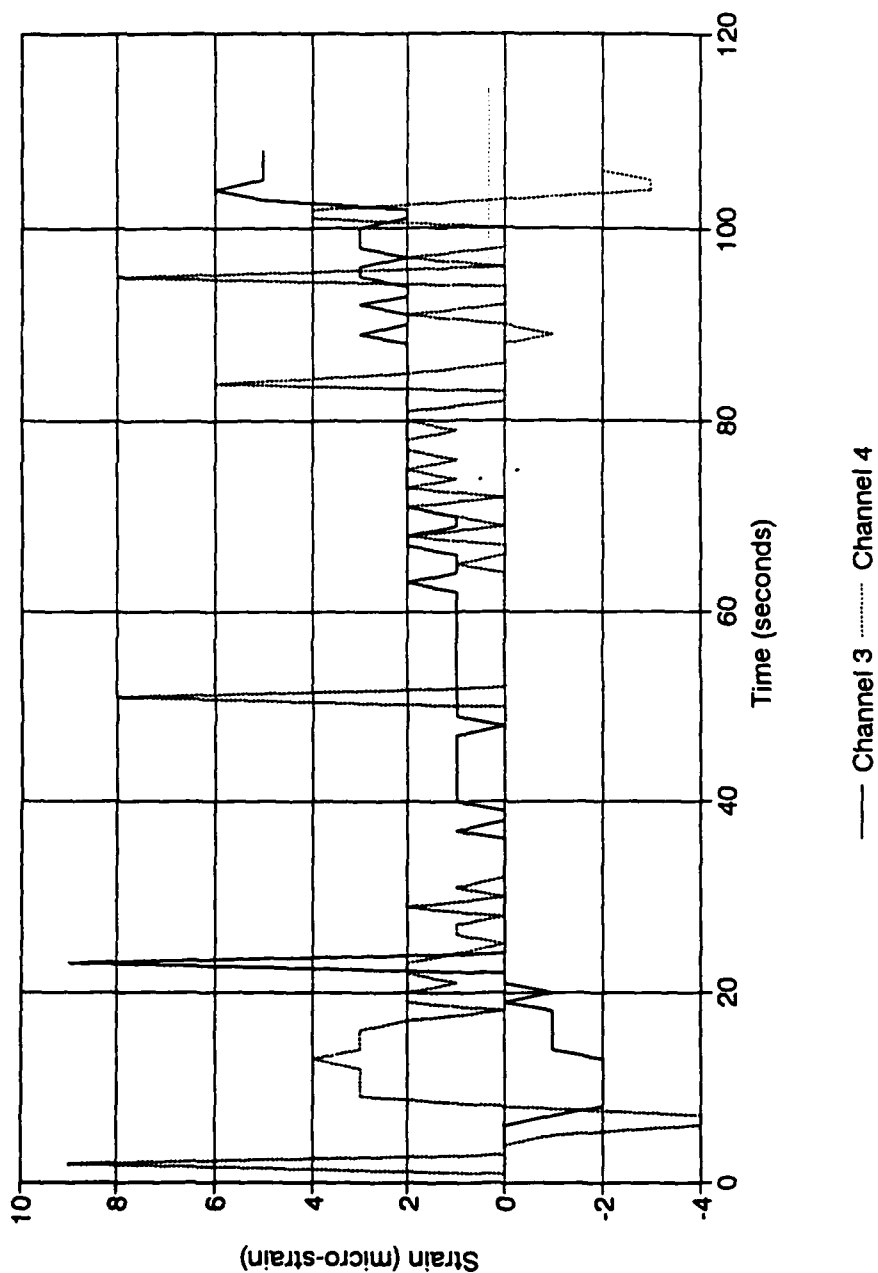
Emsworth: operating strut force (close)  
Force computed from strain measurements



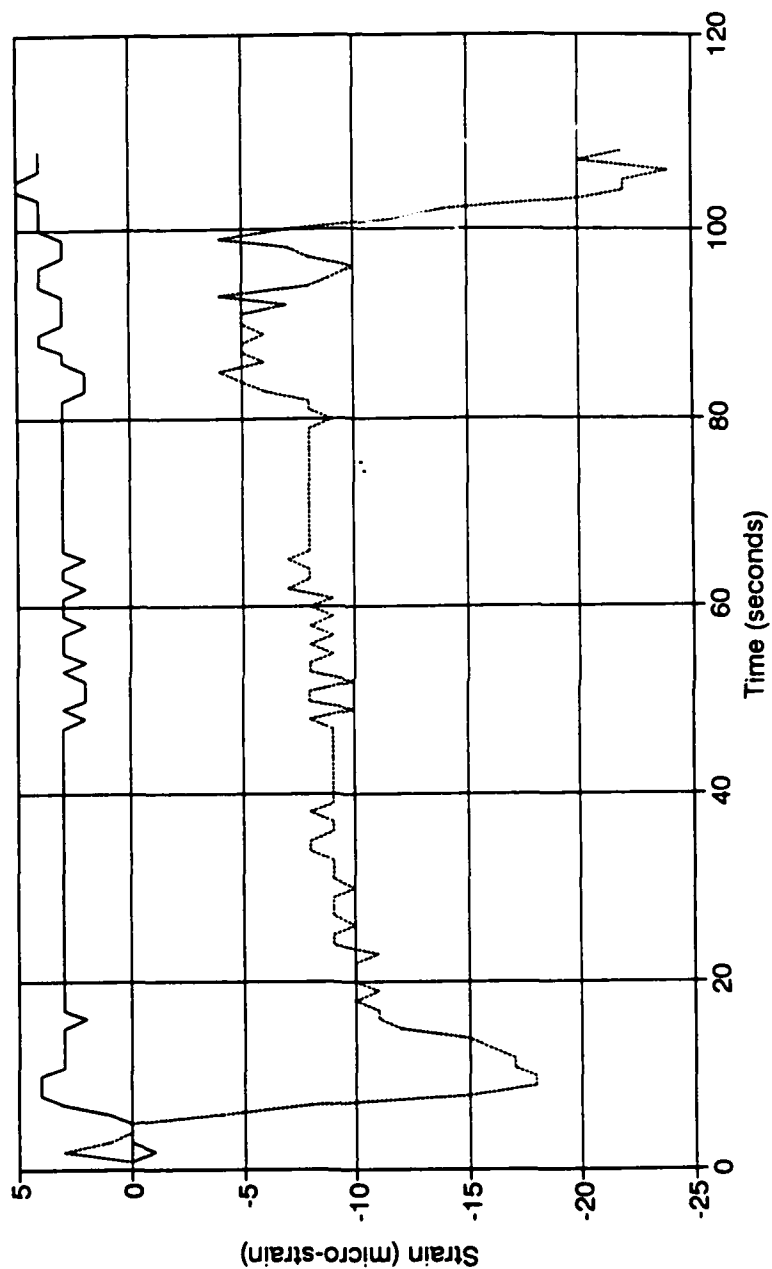
Emsworth strain history (gate closing)  
Quoin girder



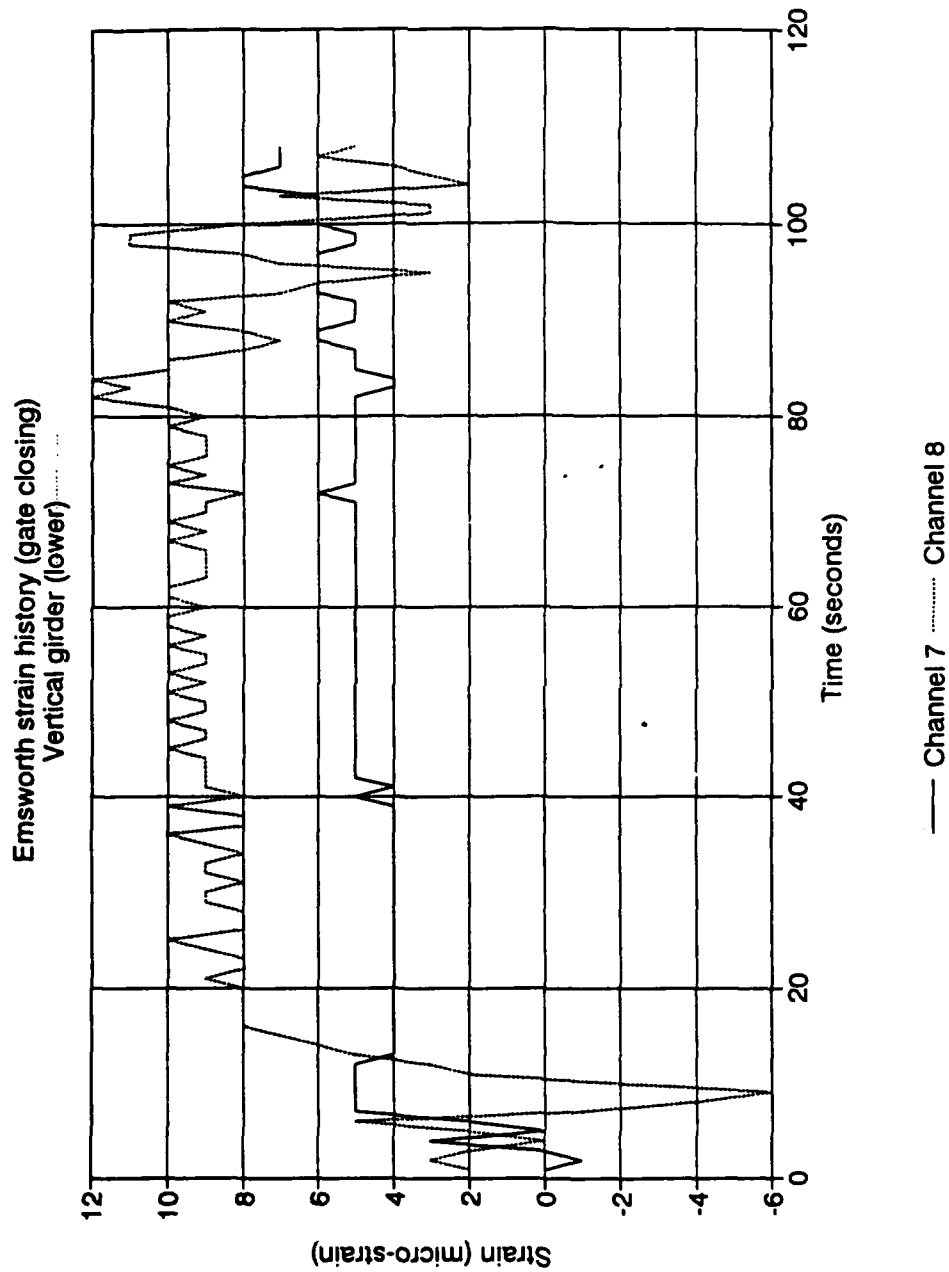
Emsworth strain history (gate closing)  
Vertical beam 3



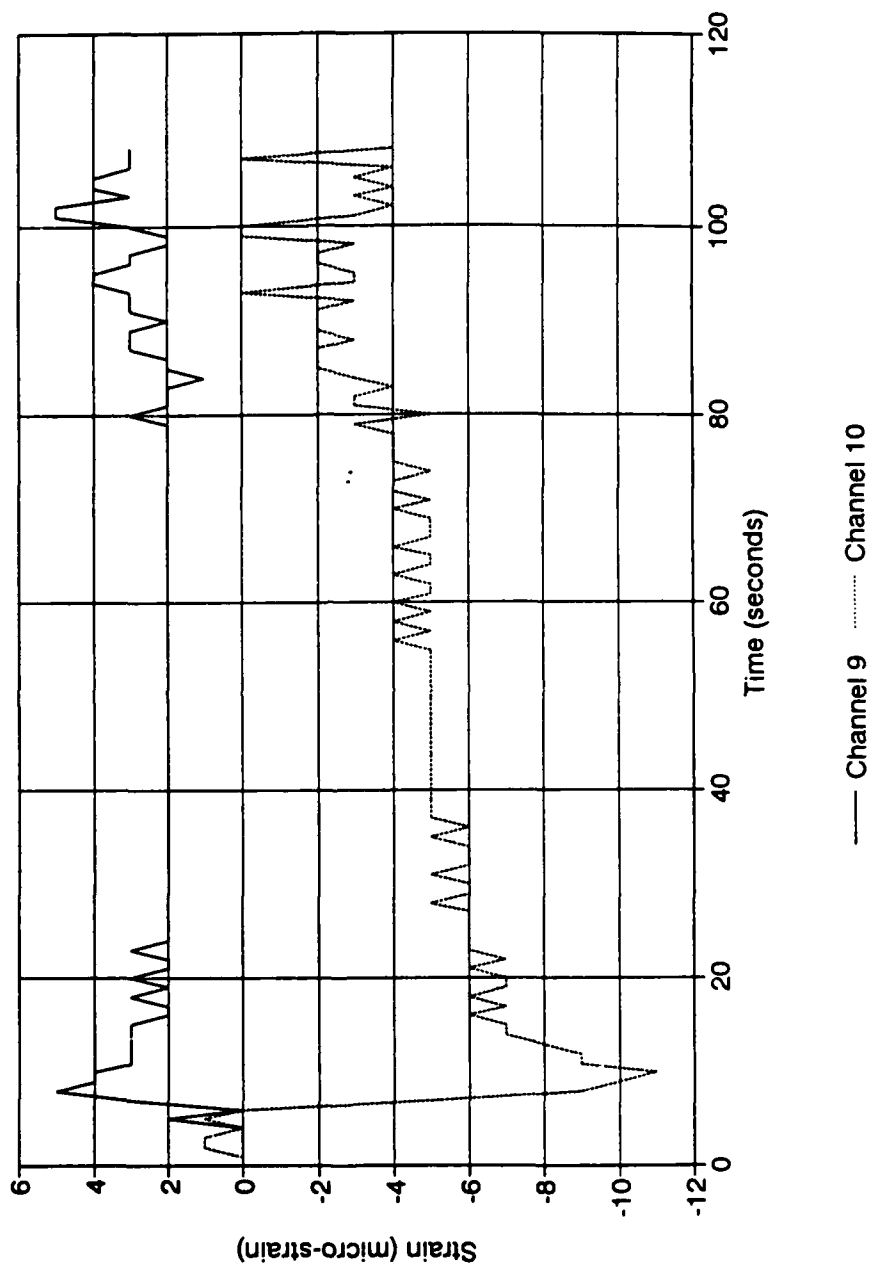
Emsworth strain history (gate closing)  
Vertical beam 5 (lower)



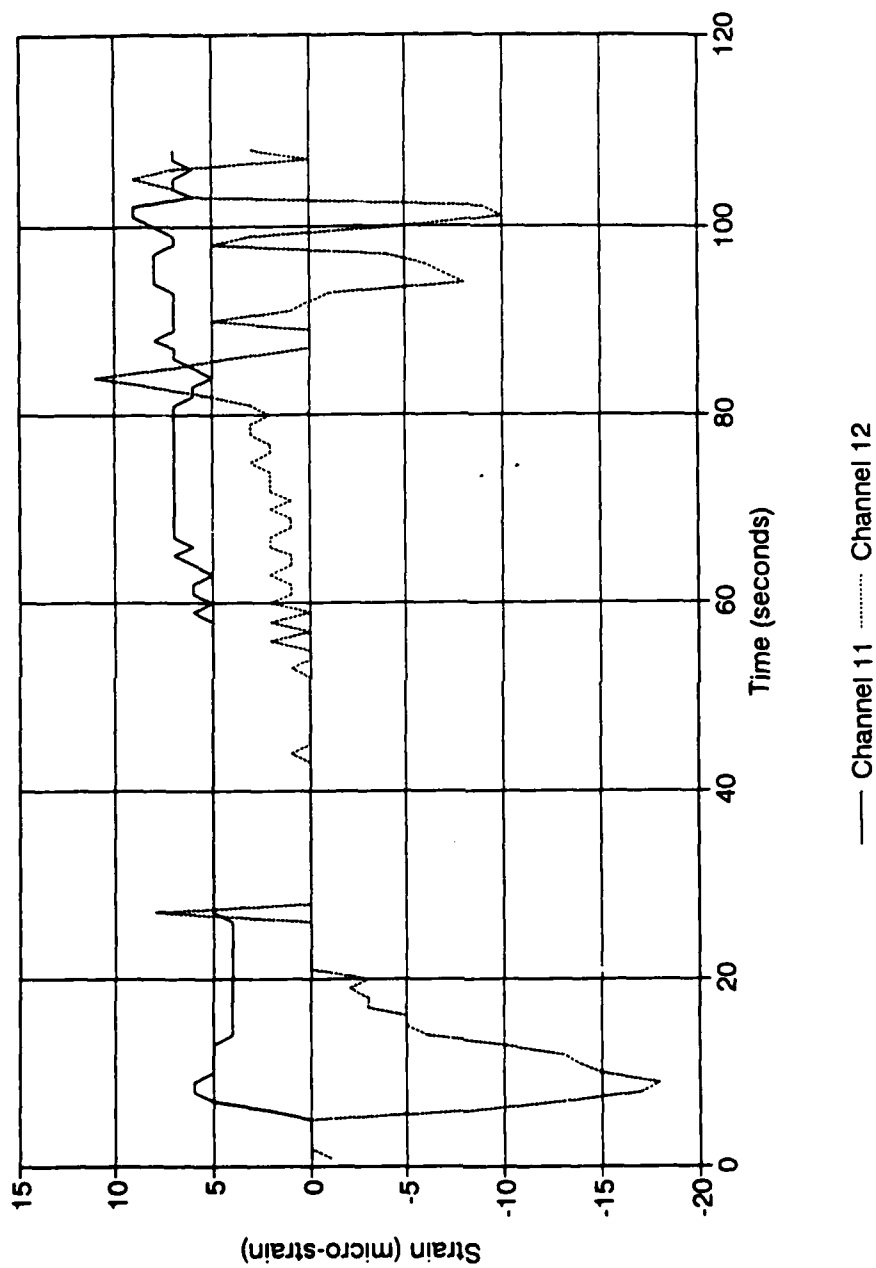
— Channel 5 ..... Channel 6



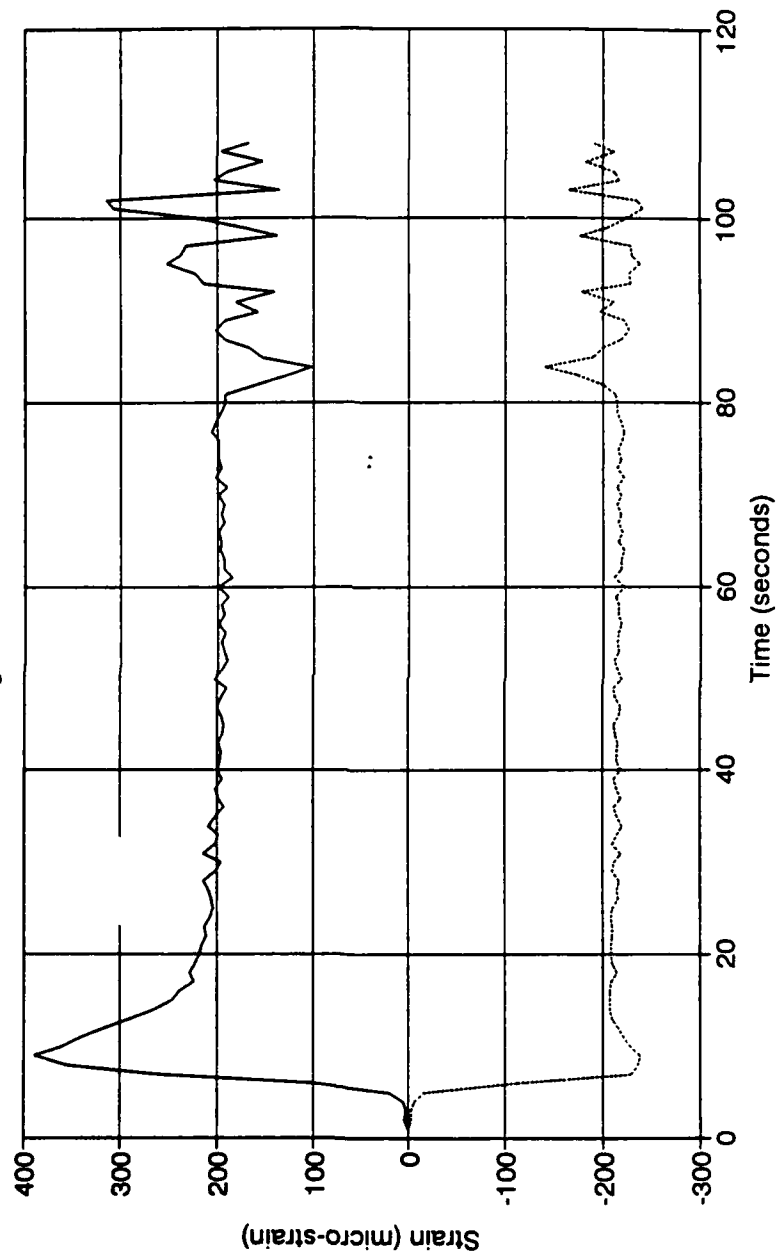
Emsworth strain history (gate closing)  
Vertical beam 6



Emsworth strain history (gate closing)  
Vertical beam 8



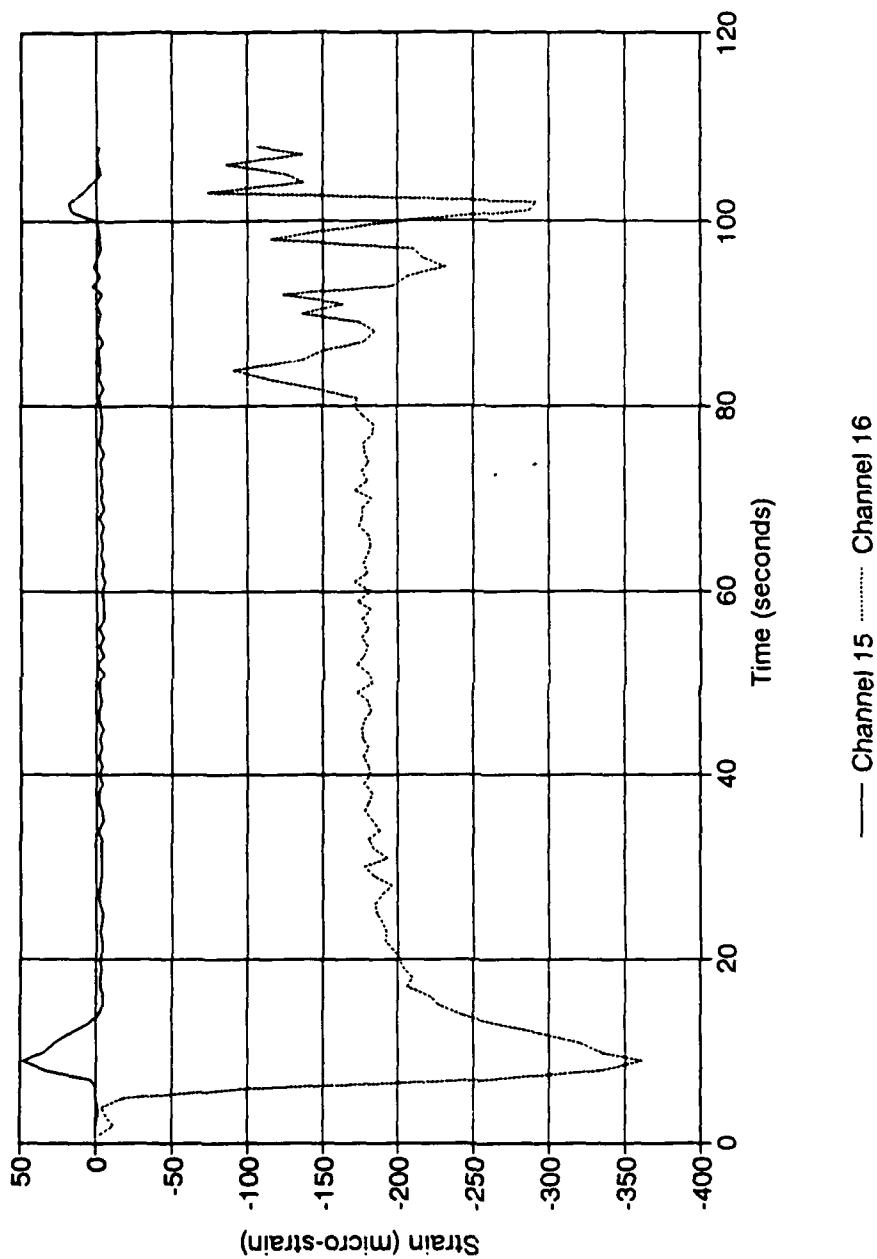
Emsworth strain history (gate closing)  
Diagonals 1 and 2



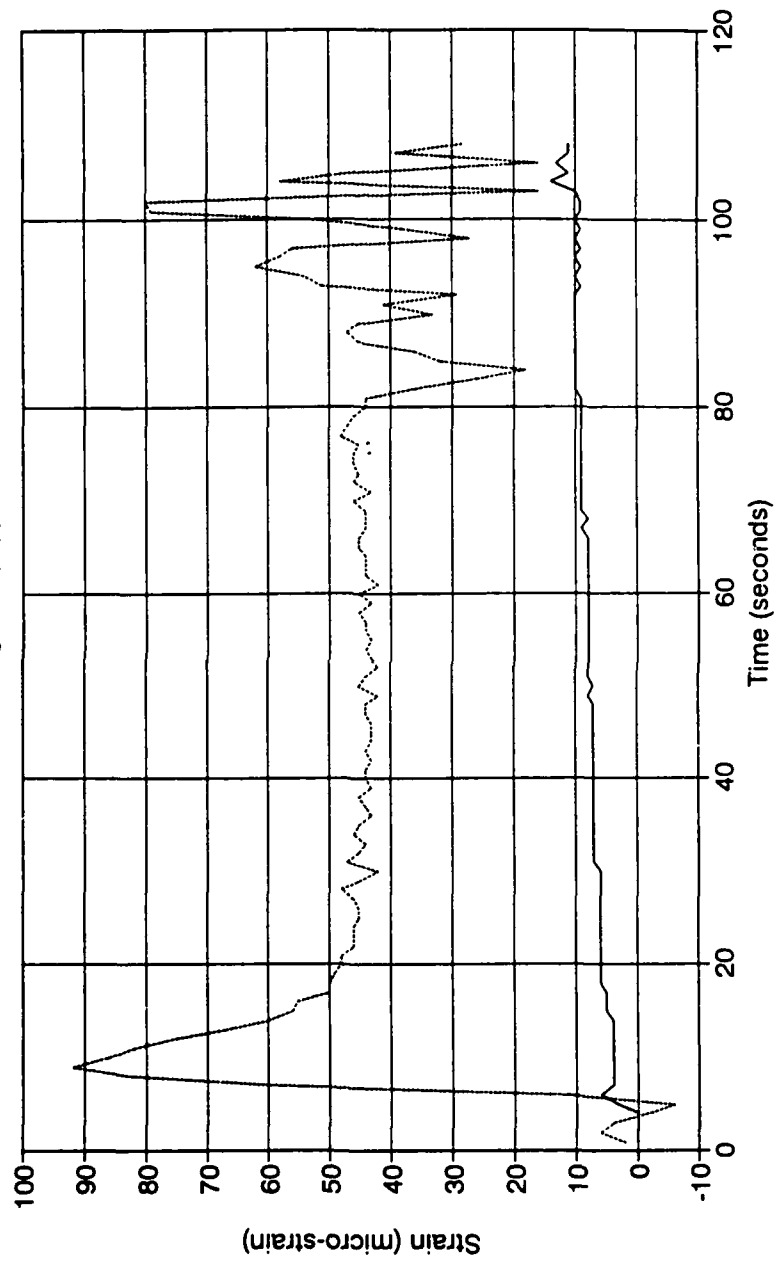
— Channel 13 ..... Channel 14



Emsworth strain history (gate closing)  
Diagonals 3 and 4

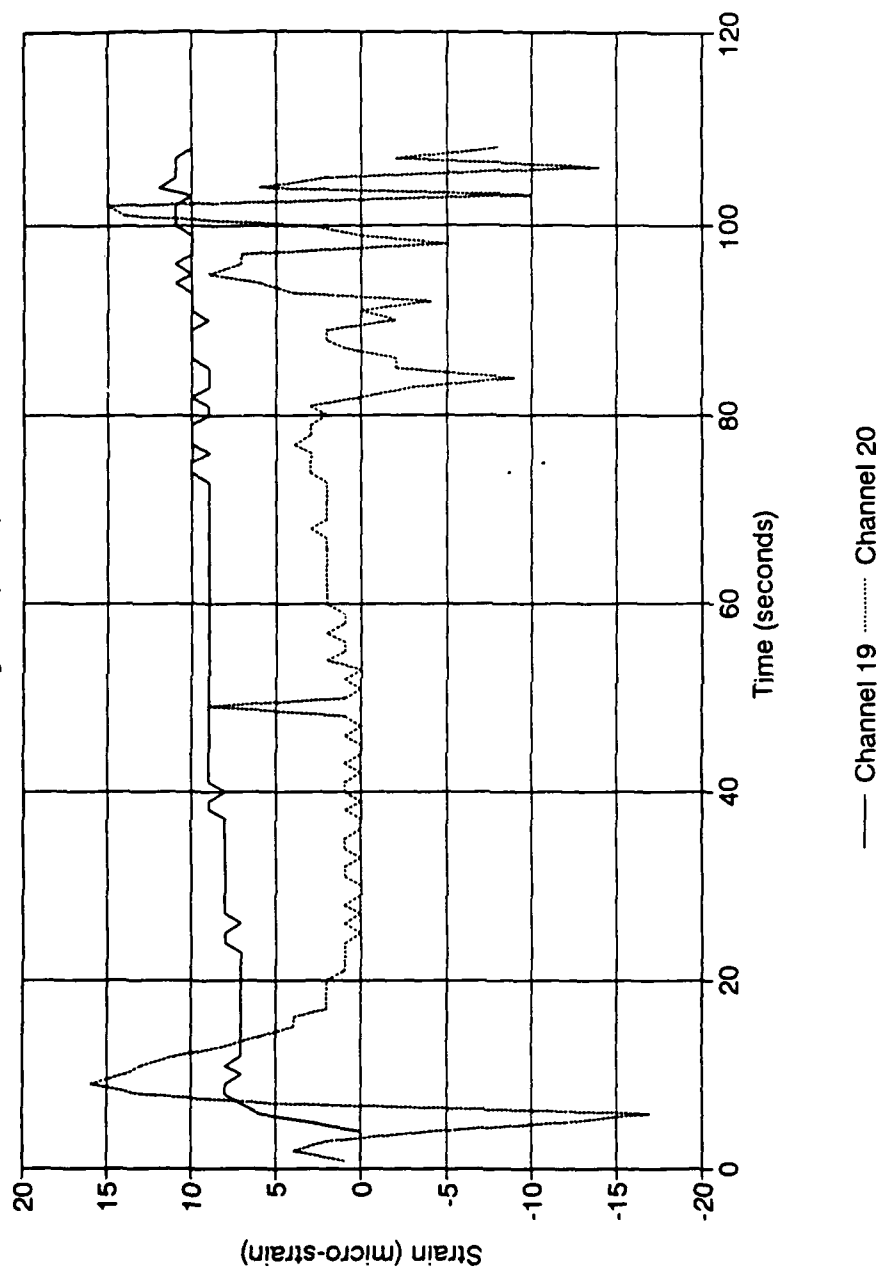


Emsworth strain history (gate closing)  
Miter girder (top)

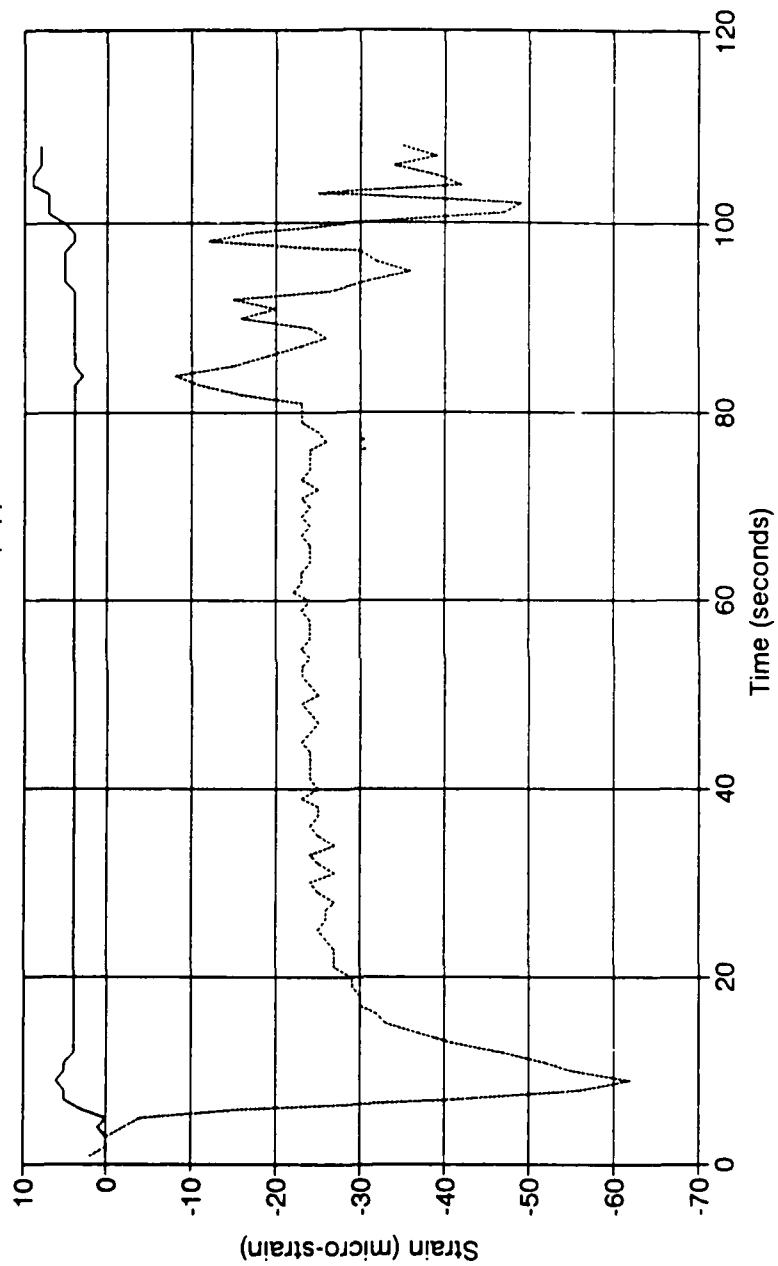


— Channel 17 ..... Channel 18

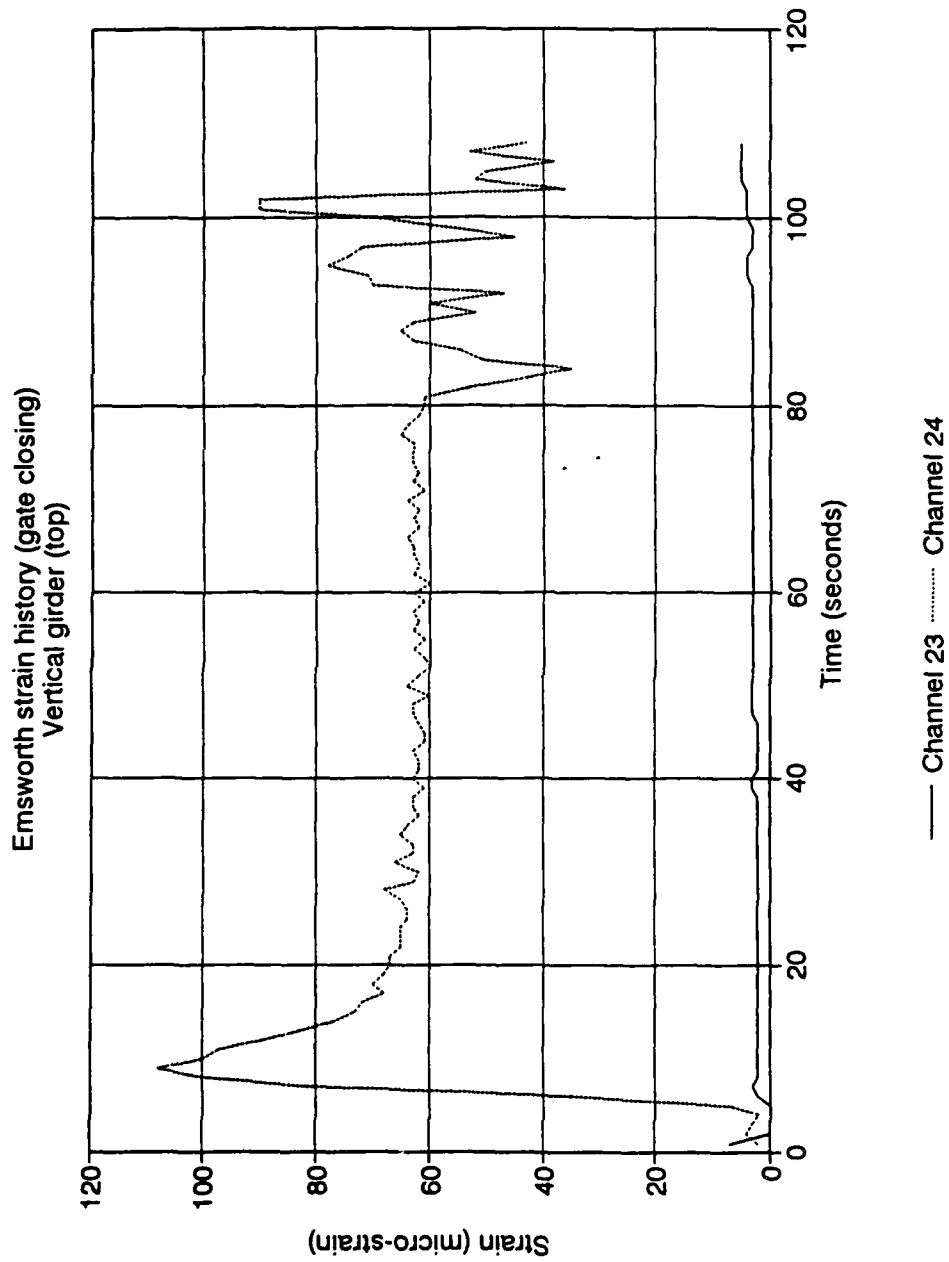
Emsworth strain history (gate closing)  
Miter girder (lower)



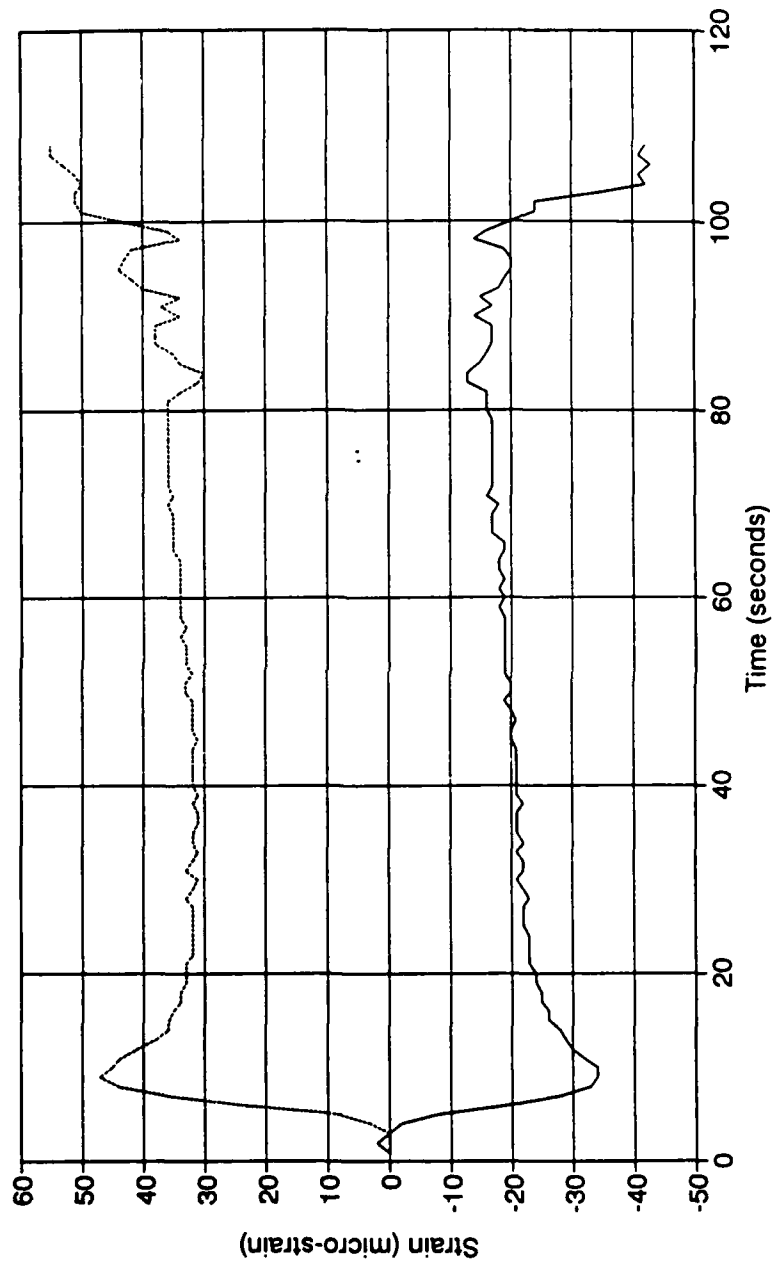
Emsworth strain history (gate closing)  
Vertical beam 5 (top)



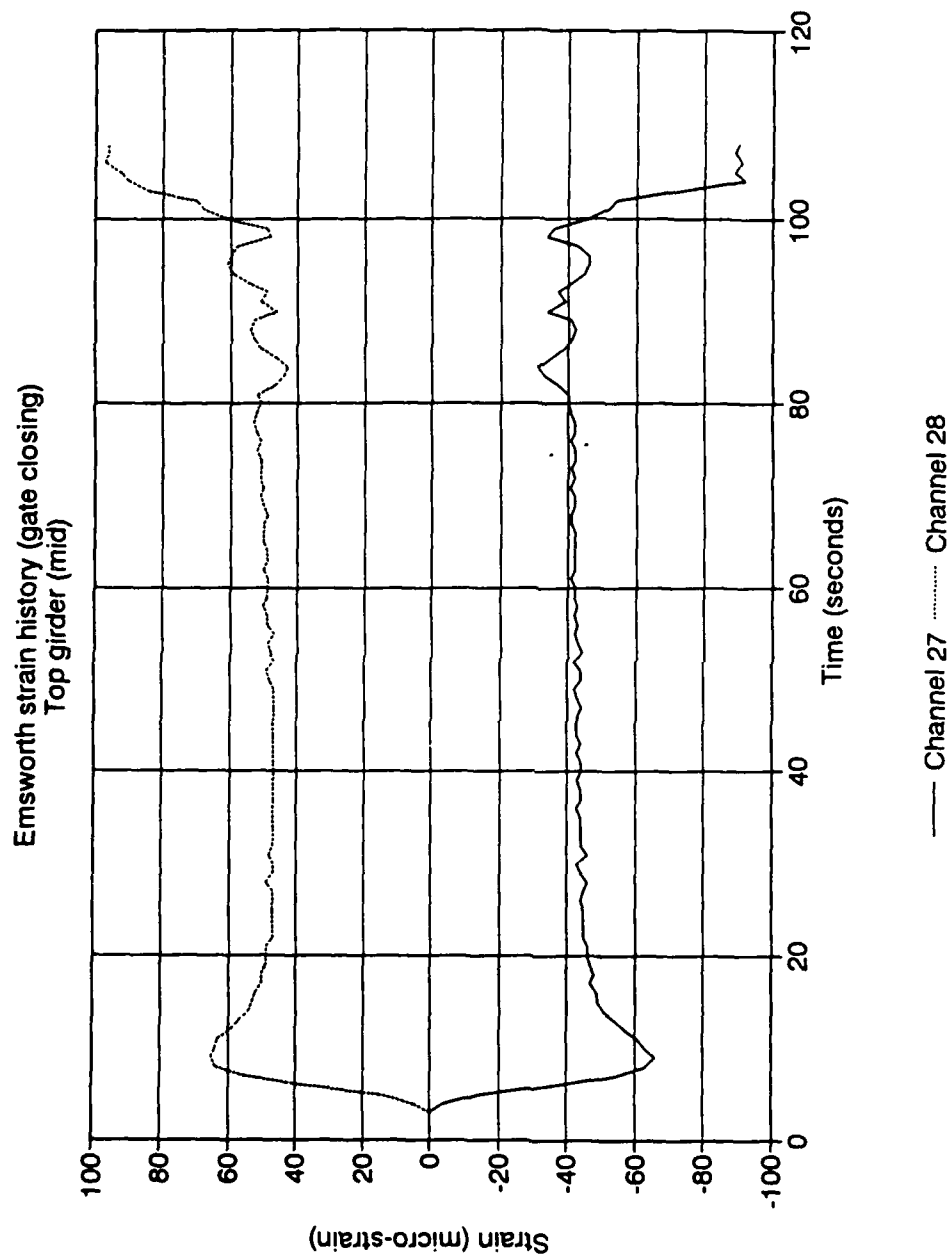
— Channel 21 ..... Channel 22



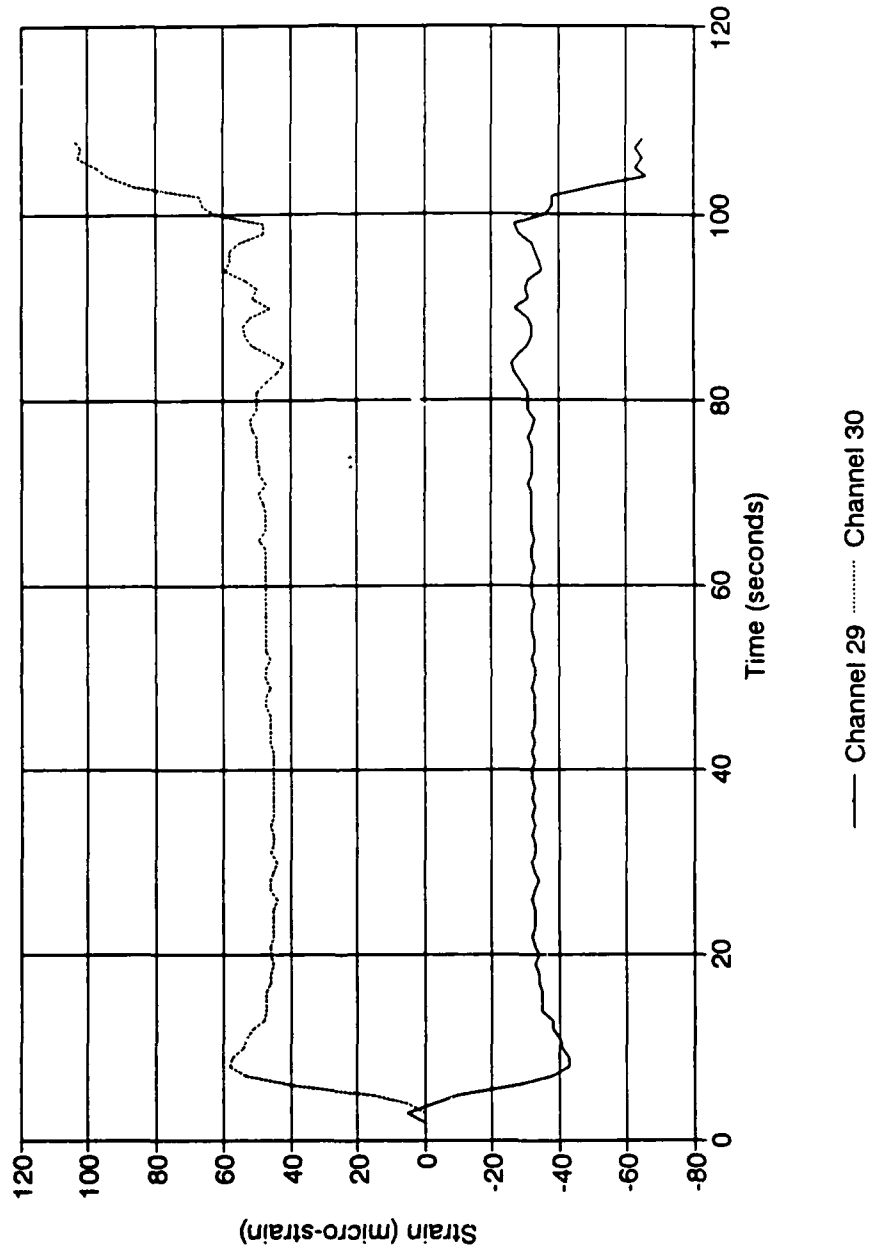
Emsworth strain history (gate closing)  
Top girder (mtr. end)



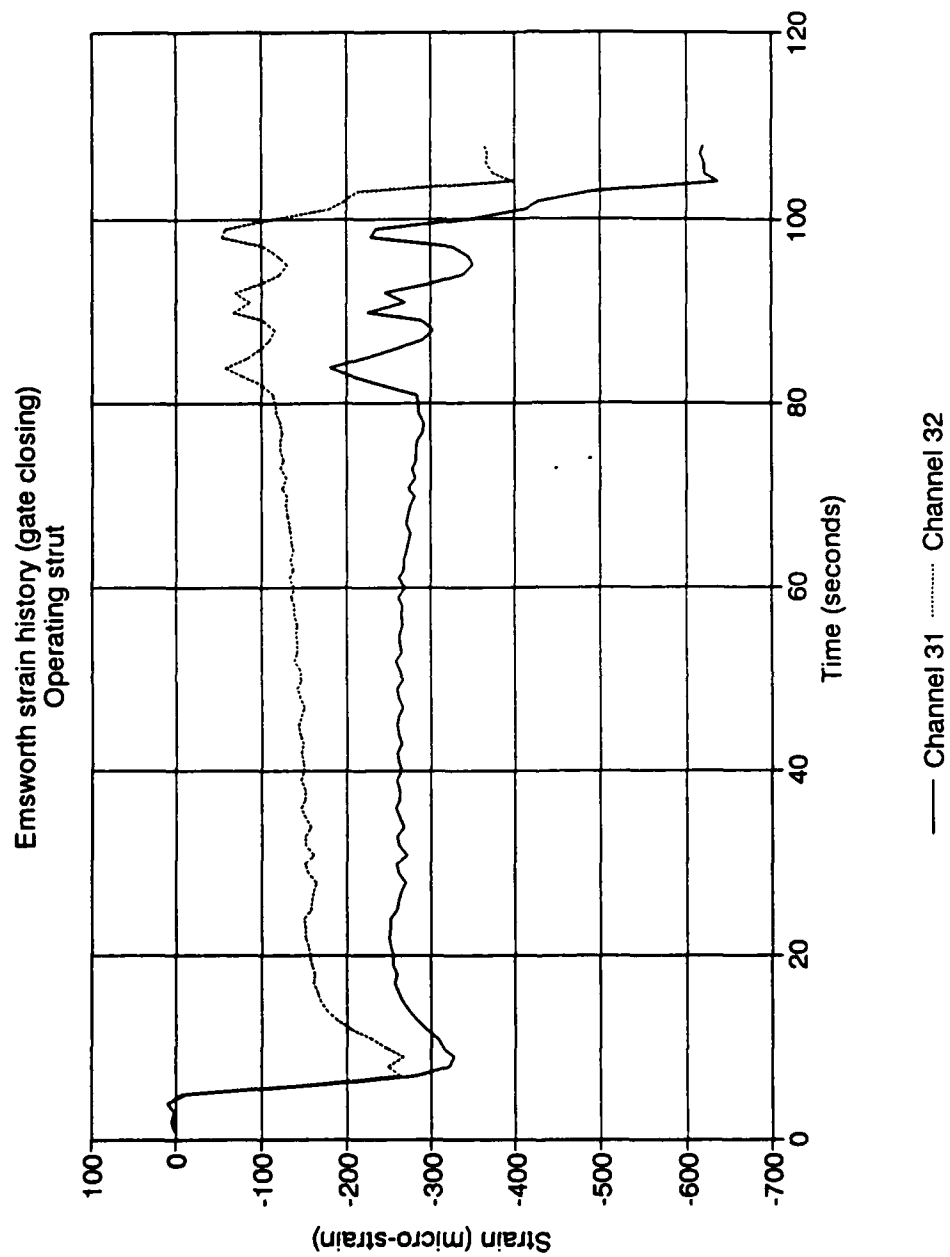
— Channel 25 ..... Channel 26



Emsworth strain history (gate closing)  
Top girder (quoin end)







REPORT DOCUMENTATION PAGE			Form Approved OMB No 0704-0188	
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4. TITLE AND SUBTITLE Computer-Aided, Field-Verified Structural Evaluation; Report 3, Field Test and Analysis Correlation of a Vertically Framed Miter Gate at Emsworth Lock and Dam		5. FUNDING NUMBERS		
6. AUTHOR(S) Brett C. Commander, Jeff X. Schulz, George G. Goble, Cameron P. Chasten				
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Bridge Diagnostics, Inc. 5398 Manhattan Circle, Suite 280, Boulder, CO 80303 U.S. Army Engineer Waterways Experiment Station Information Technology Laboratory 3909 Halls Ferry Road, Vicksburg, MS 39180-6199		8. PERFORMING ORGANIZATION REPORT NUMBER  Technical Report ITL-92-12		
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13. ABSTRACT (Maximum 200 words)  <p>The project entitled "Computer-Aided, Field-Verified Structural Evaluation" is an effort in which analytical and experimental methods are combined to form a unique structural evaluation system. As part of this project, this technical report describes experimental and analytical studies that were conducted for a vertically framed miter gate leaf at the Emsworth Lock and Dam located on the Ohio River near Emsworth, PA.</p> <p>Strain was measured at various locations on the leaf while the leaf was subject to two loading conditions consisting of hydrostatic head differential and gate leaf operation. A quick review of experimental measurements in the field indicated that one of the diagonal members was slack. This provides an excellent example of the value of field testing in the assessment of structural integrity. Assessment of the effect of the loose diagonal on structural behavior is discussed by examining experimental and analytical data. A simple grid model (hybrid grid model) was developed for analysis purposes. Based on experimental measurements, reasonable results were obtained.</p>				
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20. LIMITATION OF ABSTRACT				

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Instruction Report K-80-7	User's Reference Manual: Computer Program for Design and Analysis of Inverted-T Retaining Walls and Floodwalls (TWDA)	Dec 1980
Technical Report K-80-4	Documentation of Finite Element Analyses Report 1: Longview Outlet Works Conduit Report 2: Anchored Wall Monolith, Bay Springs Lock	Dec 1980 Dec 1980
Technical Report K-80-5	Basic Pile Group Behavior	Dec 1980
Instruction Report K-81-2	User's Guide: Computer Program for Design and Analysis of Sheet Pile Walls by Classical Methods (CSHTWAL) Report 1: Computational Processes Report 2: Interactive Graphics Options	Feb 1981 Mar 1981
Instruction Report K-81-3	Validation Report: Computer Program for Design and Analysis of Inverted-T Retaining Walls and Floodwalls (TWDA)	Feb 1981
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Technical Report K-83-3	Reference Manual: Computer Graphics Program for Generation of Engineering Geometry (SKETCH)	Sep 1983
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Technical Report ITL-90-3	Investigation and Design of U-Frame Structures Using Program CUFRBC Volume A: Program Criteria and Documentation Volume B: User's Guide for Basins Volume C: User's Guide for Channels	May 1990
Instruction Report ITL-90-6	User's Guide: Computer Program for Two-Dimensional Analysis of U-Frame or W-Frame Structures (CWFRAM)	Sep 1990
Instruction Report ITL-90-2	User's Guide: Pile Group--Concrete Pile Analysis Program (CPGC) Preprocessor to CPGA Program	Jun 1990
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Technical Report ITL-92-4	Introduction to the Computation of Response Spectrum for Earthquake Loading	Jun 1992
Instruction Report ITL-92-3	Concept Design Example, Computer Aided Structural Modeling (CASM) Report 1: Scheme A Report 2: Scheme B Report 3: Scheme C	Jun 1992 Jun 1992 Jun 1992
Instruction Report ITL-92-4	User's Guide: Computer-Aided Structural Modeling (CASM) - Version 3.00	Apr 1992
Instruction Report ITL-92-5	Tutorial Guide: Computer-Aided Structural Modeling (CASM) - Version 3.00	Apr 1992

(Continued)

# WATERWAYS EXPERIMENT STATION REPORTS PUBLISHED UNDER THE COMPUTER-AIDED STRUCTURAL ENGINEERING (CASE) PROJECT

(Concluded)

	Title	Date
Contract Report ITL-92-1	Optimization of Steel Pile Foundations Using Optimality Criteria	Jun 1992
Technical Report ITL-92-7	Refined Stress Analysis of Melvin Price Locks and Dam	Sep 1992
Contract Report ITL-92-2	Knowledge-Based Expert System for Selection and Design of Retaining Structures	Sep 1992
Contract Report ITL-92-3	Evaluation of Thermal and Incremental Construction Effects for Monoliths AL-3 and AL-5 of the Melvin Price Locks and Dam	Sep 1992
Instruction Report GL-87-1	User's Guide: UTEXAS3 Slope-Stability Package; Volume IV, User's Manual	Nov 1992
Technical Report ITL-92-11	The Seismic Design of Waterfront Retaining Structures	Nov 1992
Technical Report ITL-92-12	Computer-Aided, Field-Verified Structural Evaluation Report 1: Development of Computer Modeling Techniques for Miter Lock Gates	Nov 1992
	Report 2: Field Test and Analysis Correlation at John Hollis Bankhead Lock and Dam	Dec 1992
Instruction Report GL-87-1	User's Guide: UTEXAS3 Slope-Stability Package; Volume III, Example Problems	Dec 1992
Technical Report ITL-93-1	Theoretical Manual for Analysis of Arch Dams	Jul 1993
Technical Report ITL-93-2	Steel Structures for Civil Works, General Considerations for Design and Rehabilitation	Aug 1993
Technical Report ITL-93-3	Soil-Structure Interaction Study of Red River Lock and Dam No. 1 Subjected to Sediment Loading	Sep 1993
Instruction Report ITL-93-4	Load and Resistance Factor Design for Steel Miter Gates	Oct 1993
Technical Report ITL-92-12	Computer-Aided, Field-Verified Structural Evaluation Report 3: Field Test and Analysis Correlation of a Vertically Framed Miter Gate at Emsworth Lock and Dam	Dec 1993

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